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THE RAILWAY TUNNELS OF NEW YORK CITY.[1]

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WHEN I accepted the invitation to address the Institute on the subject of the "Railway Tunnels of New York City," the full scope which might be contemplated did not occur to me. My first thought was rather of the high honor recently conferred on me by the Institute which made its invitation a command to be obeyed unhesitatingly.

By the term "tunnel" we usually refer to an underground passage formed by excavating a heading and enlarging this to the full section required; but a tunnel can be formed in other ways, as, for example, the tunnel under Detroit River, formed of sections built in part at a distance, towed to the site, sunk in a prepared trench, and then completed with floating plant and working force. The term may therefore be considered as referring to the completed structure rather than to the method for constructing it; and the view may be held that the subject assigned to me refers not merely to tunnels under the waterways around

[1] Presented at the stated meeting of the Institute held Wednesday, November 20, 1912.

[Dr. Noble received the Institute's Elliott Cresson Medal May 15, 1912, in recognition of his distinguished achievements in the field of civil engineering.—ED.]

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Manhattan Island, but to all the sub-surface structures used for railway purposes within the limits of the city. Accepting this view for our present purpose, it is proposed to give in this paper a brief outline of the several railway tunnel and subway systems in New York City and to follow this with more particular reference to the construction of tunnels under the rivers enclosing the island of Manhattan.

To avoid confusion in referring to the several districts of Greater New York, the one formerly embraced within the older city of New York will be referred to as the island or borough of Manhattan, or simply as Manhattan; the former city of Brooklyn as the borough of Brooklyn, or Brooklyn; the northwesterly portion of Long Island, lying along East River north of Newtown Creek and extending eastward some distance along Long Island Sound, as the borough of Queens, or Queens, and the portion of Westchester County lying east of Harlem River and extending eastward for some distance along Long Island Sound, as the borough of The Bronx, or The Bronx.

OUTLINES OF EXISTING TUNNEL SYSTEMS.

New York Central & Hudson River Railroad Tunnel.

This is located under Park Avenue in New York City, and was built in 1872–5. It is the oldest railroad tunnel now in use in the city. It contains four tracks and extends from Fifty-sixth Street to Ninety-sixth Street, a total distance of two miles. A short section, 550 feet long, was built by ordinary tunnelling methods, the remainder in open cutting. It was a notable work when built.

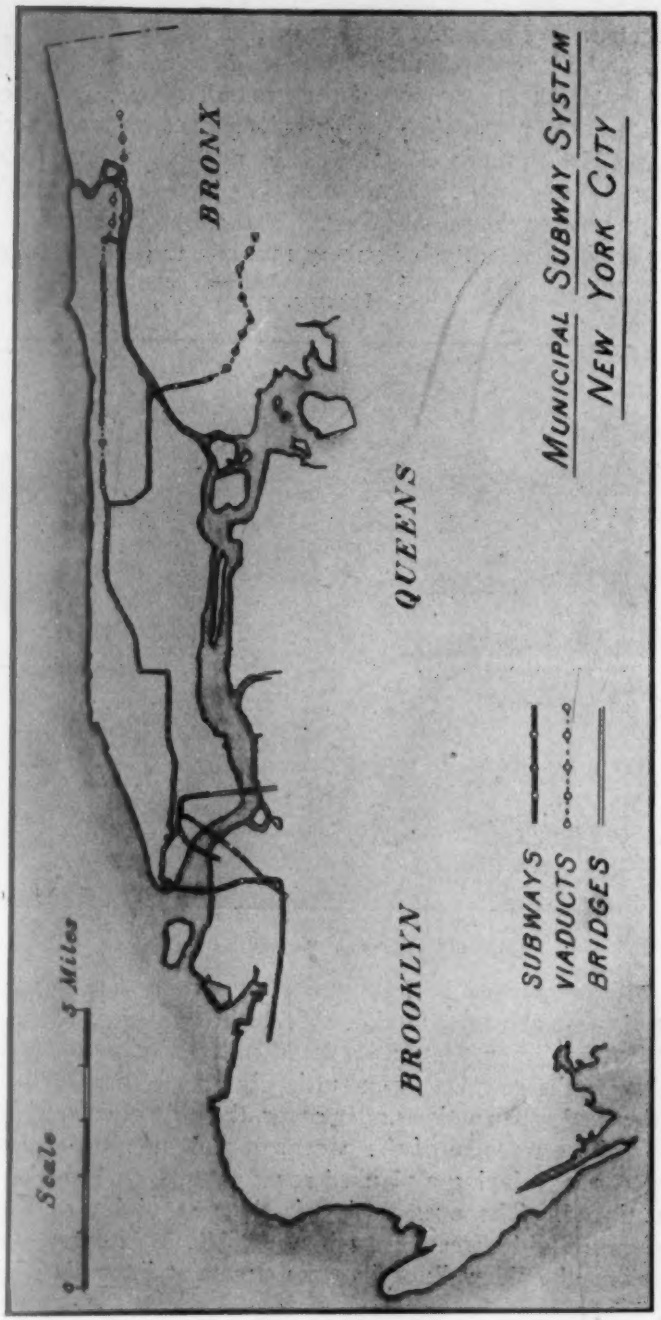
Long Island Railroad Tunnel in Brooklyn.

The so-called Atlantic Avenue Improvement of the Long Island Railroad, consisting in part of tunnel built in open-cutting and partly of elevated railroad, was carried out in 1904–8. The tunnel structure is about 2¼ miles long and provides for two tracks.

New York City Subway Tunnels.

The rapid transit subway system now in use, or nearly ready for use, is indicated in Plate 1. The portions in Manhattan and Brooklyn consist almost entirely of tunnels, the total length of

PLATE I.

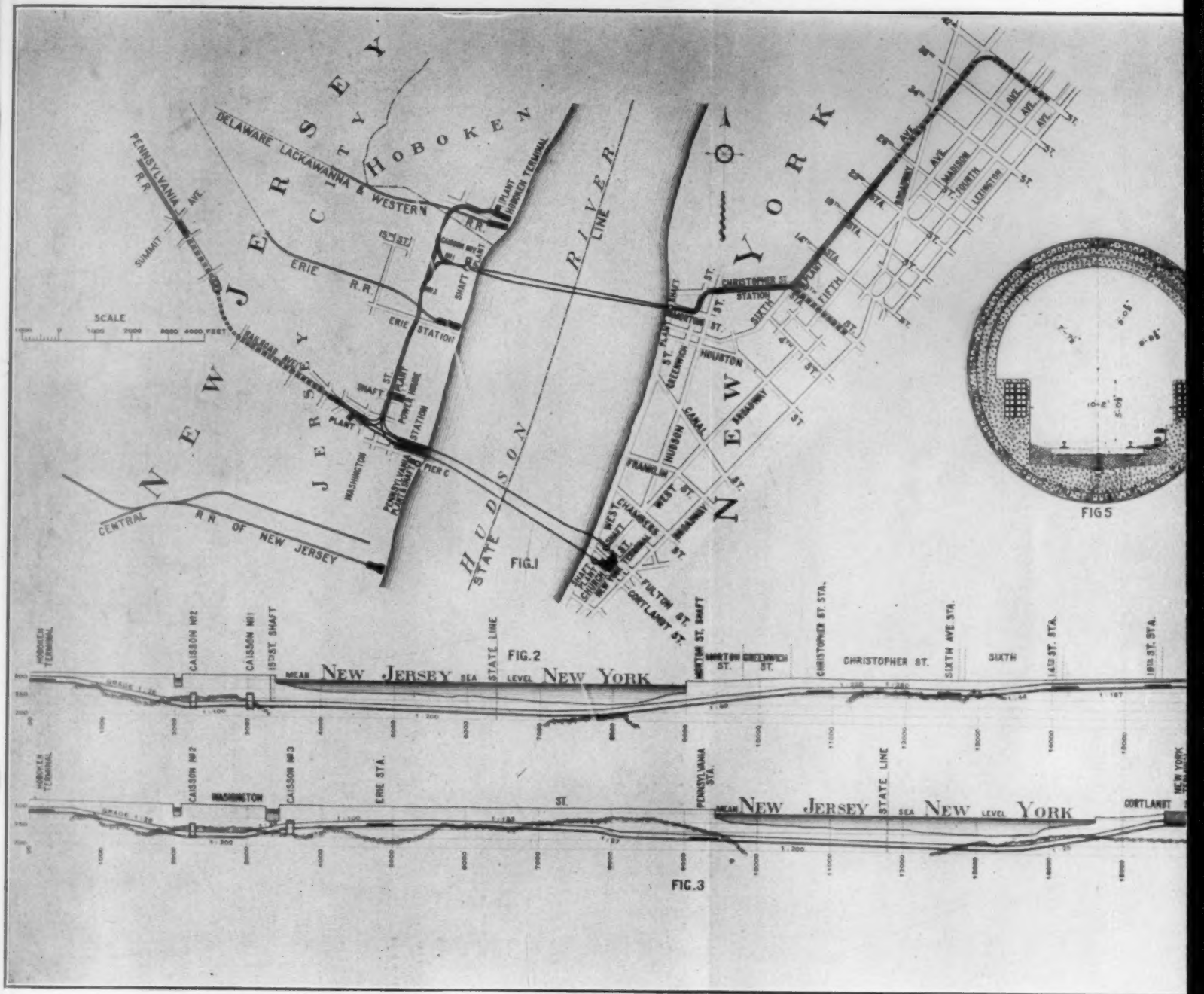

BRONX
QUEENS
BROOKLYN
Scale
5 Miles
SUBWAYS
VIADUCTS
BRIDGES
MUNICIPAL SUBWAY SYSTEM
NEW YORK CITY

tunnel structures being 24.7 miles; of this length about 5.1 miles have been built by tunnelling methods, the remainder in trenches excavated from the surface of the ground, usually called open-cut. The interference with business along the streets was serious, and gave rise to much criticism of the method. These trenches were of sufficient width to accommodate two or more tracks, a large proportion containing four. In the Brooklyn and Center Street sections recently built these multiple track structures are

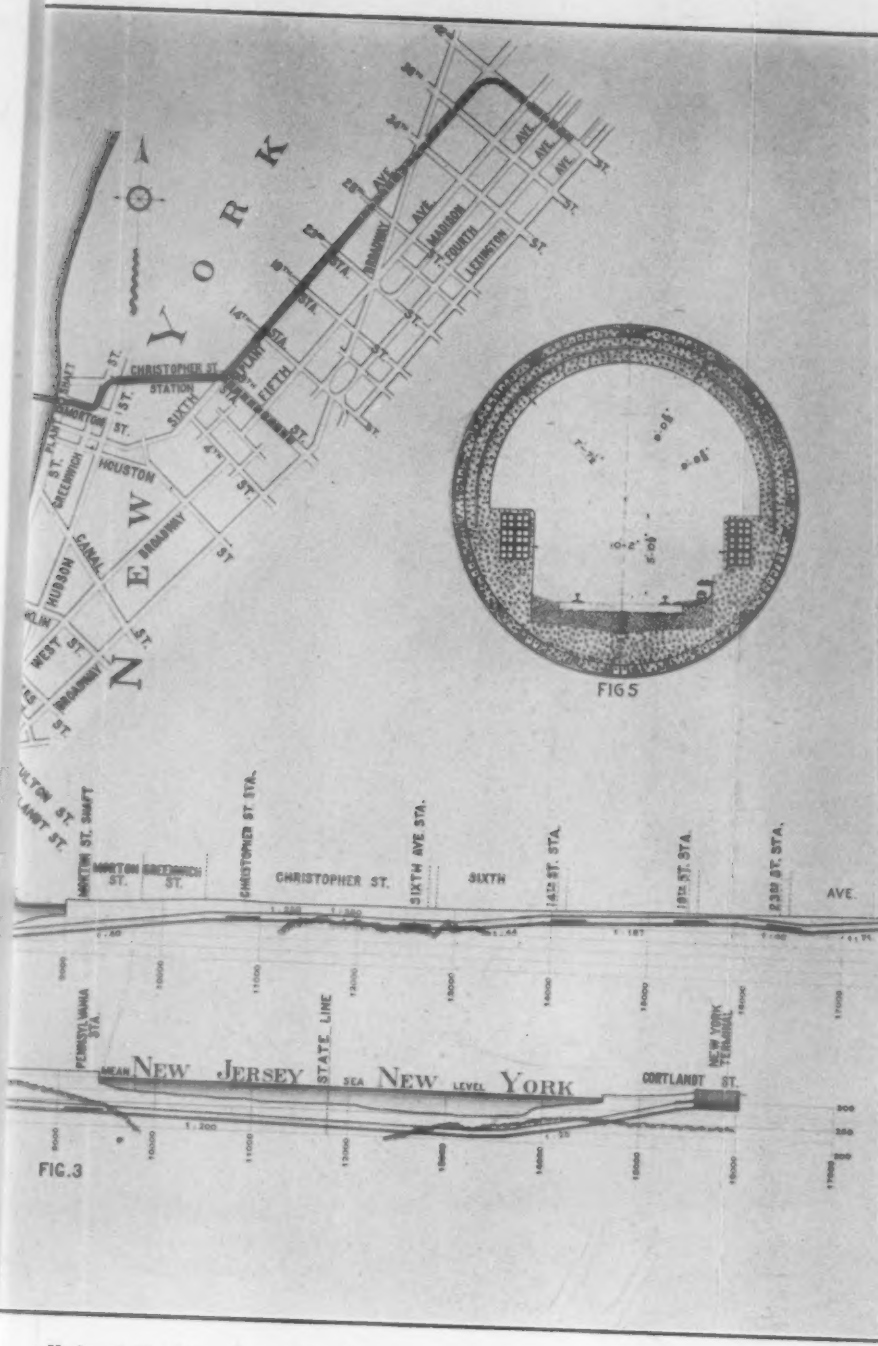
PLATE 2.

New York City Subway. Excavation under cover.

generally subdivided by longitudinal partitions forming two to eight single-track tunnels side by side in one excavation. The total track mileage of tunnels is 78 miles. In recent work in Manhattan the so-called open-cutting has really consisted of excavation and construction under cover, the only open-cutting consisting of the removal of the pavement and sufficient underlying earth to permit laying a planked roadway under which the work is continued. The open-cutting is done at night, so that the interference with street traffic is negligible. (Plate 2.) Openings along the sidewalk or in cross streets at intervals of a few



Hudson & Manhattan Railroad System.



Hudson & Manhattan Railroad System.

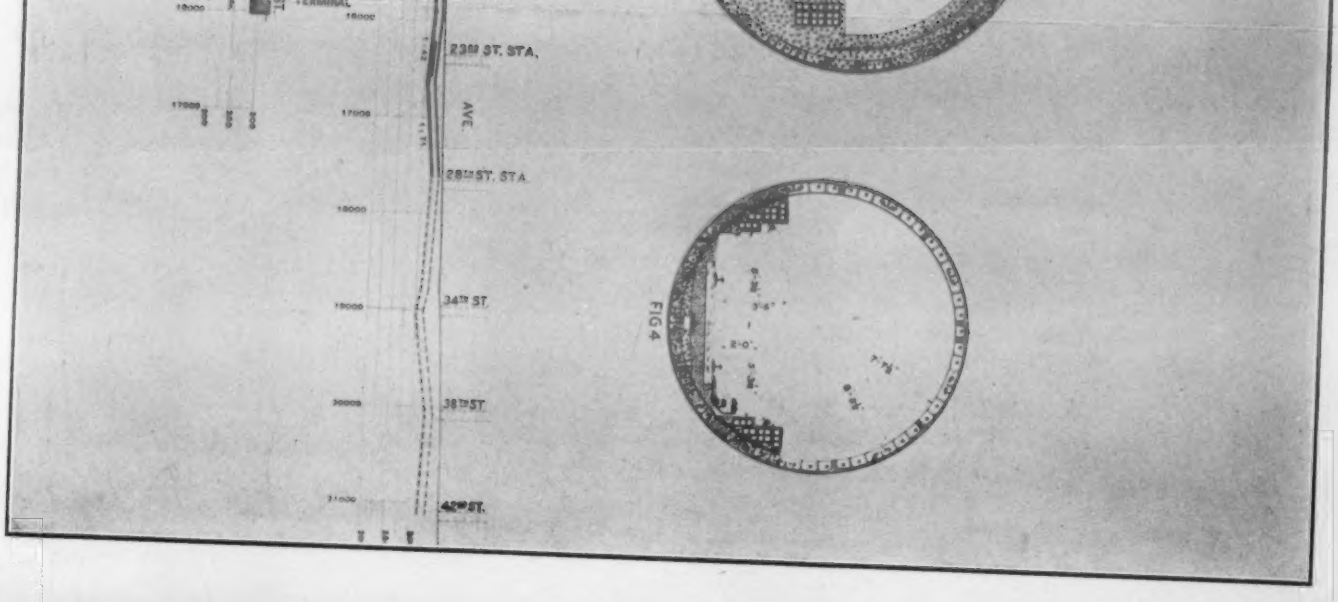


FIG 4

blocks are provided through which excavated materials are hoisted and materials for constructing the tunnels are lowered. The work is much more costly than if carried on in the open. Present convenience of the public is secured at the expense of greater capital cost and greater fixed charges, which the public must carry for a long, indefinite period.

It will be noted by reference to the map of existing subway lines (Plate 1) that there are river crossings at three localities, two of which, one from the lower end of Manhattan Island to Brooklyn under the East River, the other between the island and the borough of The Bronx near 145th Street, are by means of tunnels; while the third, from the upper end of Manhattan Island to the mainland, is by means of a three-track bridge.

Hudson & Manhattan Railroad System.

The tunnel system of the Hudson & Manhattan Railroad Company—commonly called the McAdoo tunnels in honor of the public-spirited man who pushed the project to completion—is shown in Plate 3. It embraces four tunnels under North River, with various extensions on both sides. The so-called uptown tunnels, two in number, pass eastward from Jersey City from a point near Fifteenth Street, about midway between the terminals of the Erie and the Delaware, Lackawanna & Western Railroads, and reach the Manhattan side at the foot of Morton Street, passing under Morton, Greenwich, and Christopher Streets and Sixth Avenue to the present terminal at Thirty-third Street. The two downtown tunnels start from the Manhattan terminal at Church Street, between Fulton and Cortlandt Streets, one tunnel passing under Fulton Street to the river, the other under Cortlandt Street; at the Church Street terminal they are connected by loops where the passenger platforms are placed; continuing westward under the river they pass under the Jersey City station of the Pennsylvania Railroad, with connections for passengers by means of elevators, and emerge into open air about 6800 feet farther westward. The uptown and downtown tunnels are connected on the New Jersey side by two tunnels running parallel with the river and extended northwards to the Delaware, Lackawanna & Western terminal. By means of these several connections passengers are carried quickly and directly

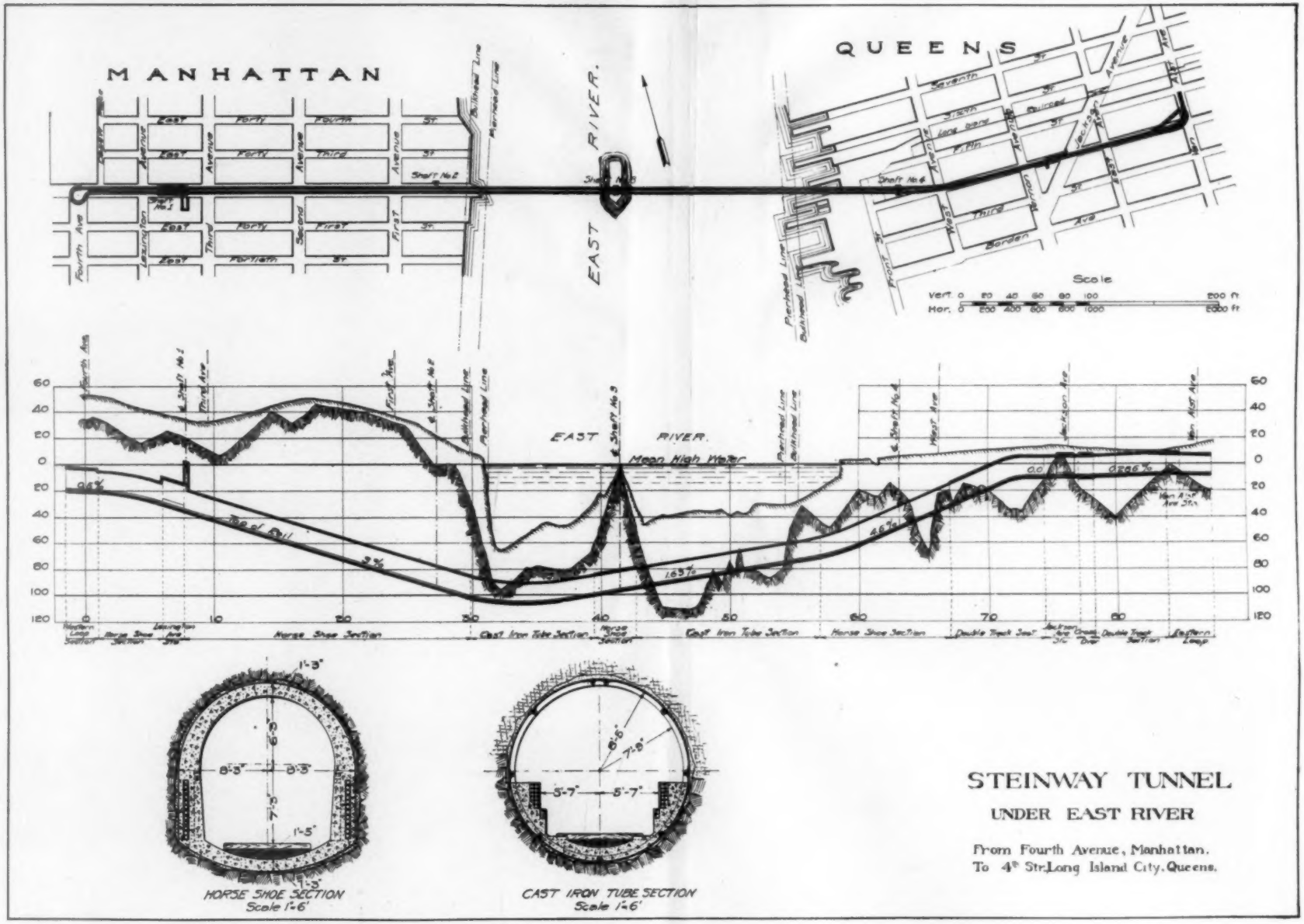
from either Manhattan terminal of the McAdoo tunnels to any of the three railroad terminals—the Pennsylvania, Erie, or Delaware, Lackawanna & Western—or by a somewhat circuitous route with two under-river crossings, from one Manhattan terminal to the other—that is, from Sixth Avenue and Thirty-third Street to Church and Cortlandt Streets. Profiles of the system are shown in Plate 3.

In the construction of this system a novel feature was introduced by sinking reinforced concrete caissons containing short sections of tunnels at several of the junction points.

In the McAdoo system there are about 7.6 miles of shield-driven tunnels. In addition to this mileage, a structure containing, by longitudinal subdivision, two single-track tunnels has been built in open-cutting under Sixth Avenue from Twelfth to Thirty-third Street, making a total of 9.6 miles of single-track tunnel now in operation.

Steinway or Belmont Tunnels.

Both the city subways and the McAdoo tunnels were designed for rolling stock of somewhat smaller dimensions than the standard railroad car. These systems provided means for quick transit between Manhattan Island and New Jersey and between Manhattan and the neighboring boroughs of Brooklyn and The Bronx, but left the rapidly-developing borough of Queens unprovided for. To meet this deficiency, Mr. August Belmont and his associates undertook, in 1905, the construction of two single-track tunnels for street car traffic from Park Avenue, Manhattan, eastward under Forty-second Street to East River, thence under the river to Long Island City, reaching the surface about 3000 feet inland. (See Plate 4 for map and profile.) This was undertaken under an old franchise granted in 1891 to Dr. Steinway. Unfortunately, unforeseen difficulties in their construction made it impossible to complete the tunnels within the term of the franchise, which expired January 1, 1907. They were completed in the summer of that year, but they have not been put in use because of dispute between the owners and the city, although urgently needed by the public. It is understood that an agreement has been reached under which these tunnels may be used.

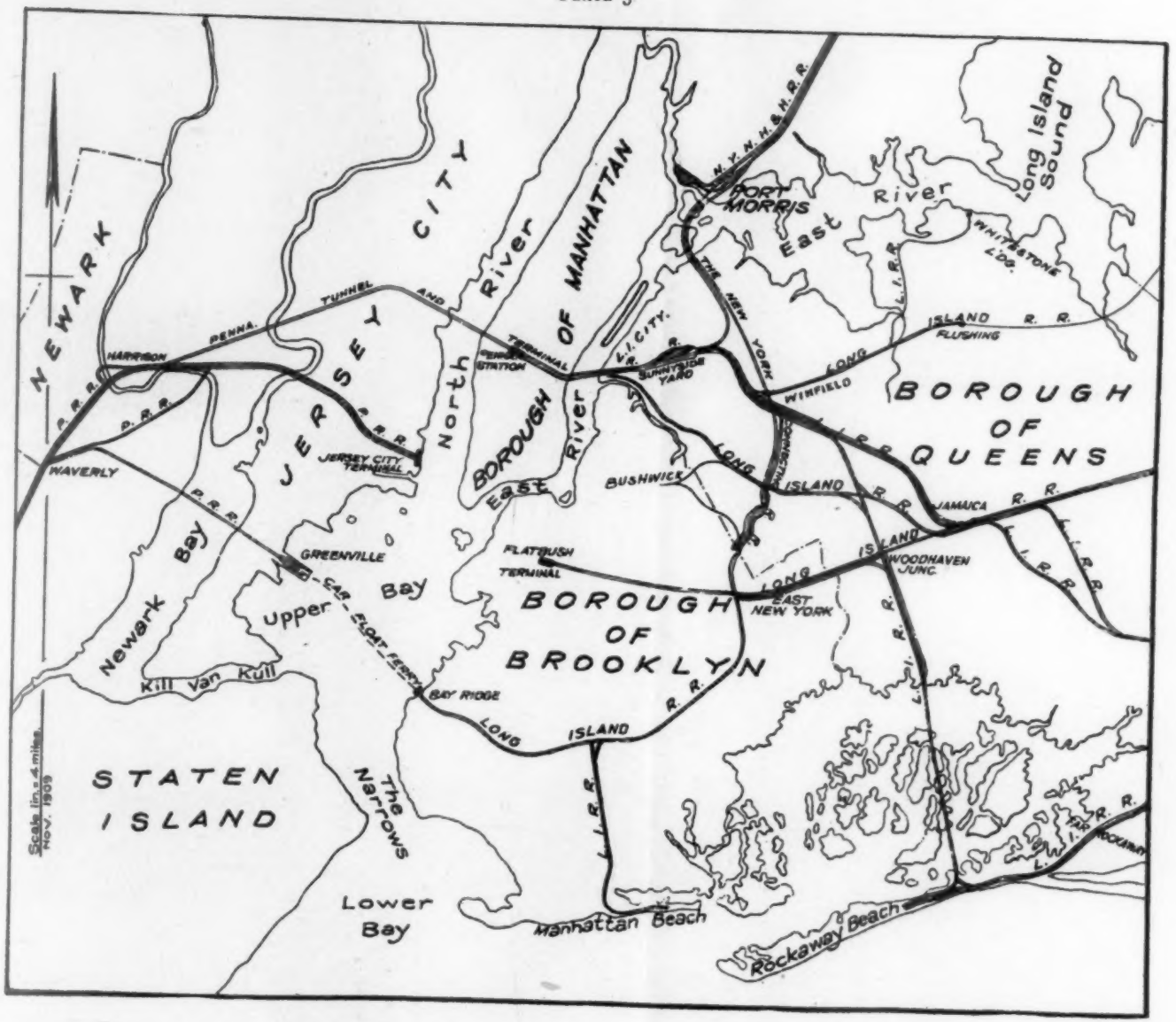


STEINWAY TUNNEL

UNDER EAST RIVER

From Fourth Avenue, Manhattan.
To 41st St. Long Island City, Queens.

PLATE 5

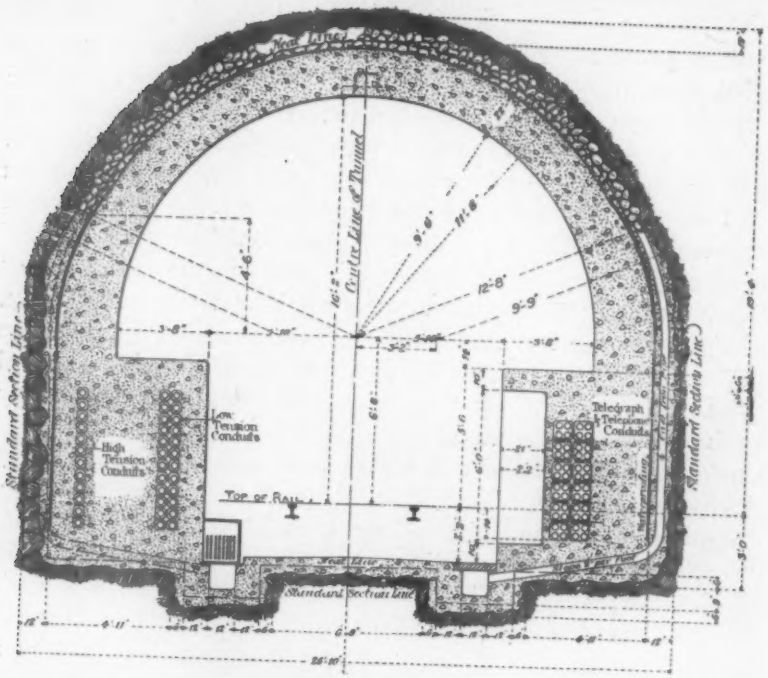

NEWARK
JERSEY CITY
North River
BOROUGH OF MANHATTAN
East River
Long Island Sound
PORT MORRIS
WHITESTONE LDG.
TUNNEL AND TERMINAL
PENNA. R.R.
HARRISON
WAVERLY
JERSEY CITY TERMINAL
L.I. CITY.
SUNNYSIDE YARD
THE NEW YORK
L.I.R.R.
ISLAND R.R.
FLUSHING
LONG
WINFIELD
BOROUGH OF QUEENS
BUSHWICK
JAMAICA R.R.
GREENVILLE
FLATBUSH TERMINAL
WOODHAVEN JUNC.
EAST NEW YORK
Newark Bay
Upper Bay
BOROUGH OF BROOKLYN
Kill Van Kull
CAR FLOAT FERRY
BAY RIDGE
STATEN ISLAND
The Narrows
Lower Bay
Manhattan Beach
Rockaway Beach
Scale 1in.=4 miles
Nov. 1909

Pennsylvania Railroad Terminal.

The project for a terminal on Manhattan Island was decided upon in the latter part of 1901, and surveys and preparations of plans were taken up at once. Construction was begun in 1903, and in 1910 the works were completed and put in use. The general features of the project may be outlined as follows:

Diverging from the former main line of the Pennsylvania Railroad at Harrison (Plate 5), about one-half mile east of Newark, a double-track railroad crosses the Hackensack Meadows on an embankment extending in a northeast direction, passing over other railroads, to the west face of the trap ridge known as Bergen Hill, which parallels the Hudson for several miles. The point where the line reaches Bergen Hill is nearly on the line of Thirty-second Street in New York City. Entering Hackensack portal, the two tracks pass under this hill in two single-track tunnels with a descending grade toward the river. A typical section and view of the completed tunnel are shown in Plate 6. The Bergen Hill section is about 6000 feet long. On the east face of the hill and about 1000 feet from the river is a large, open shaft across which the lines pass and enter the tunnels leading to and under the river to a point opposite a shaft near Eleventh Avenue in Manhattan, about 1300 feet east of the river bulkhead on the Manhattan side. The distance between the two shafts is about 6600 feet, about 4000 feet being under the water of the Hudson River. The maximum depth of the bottom of the tunnel below mean high tide is 96.9 feet. Except for a short distance from each shaft, the tunnels in this section are so-called tube tunnels and were built with the aid of shields. Eastward from Eleventh Avenue shaft the construction is twin-tunnel, so-called, this term being applied to the case where two tunnels are formed with concrete in a single excavation. This construction ends at the east side of Tenth Avenue, where the tracks enter the area of the station. From the river bulkhead to Tenth Avenue the tunnels are directly under Thirty-second Street. The station area extends eastward to Seventh Avenue, a distance of about one-half mile; eastward from Seventh Avenue the 21 station tracks converge into two three-track tunnels, one under Thirty-second Street, the other under Thirty-third Street. A typical cross-section and a view in the

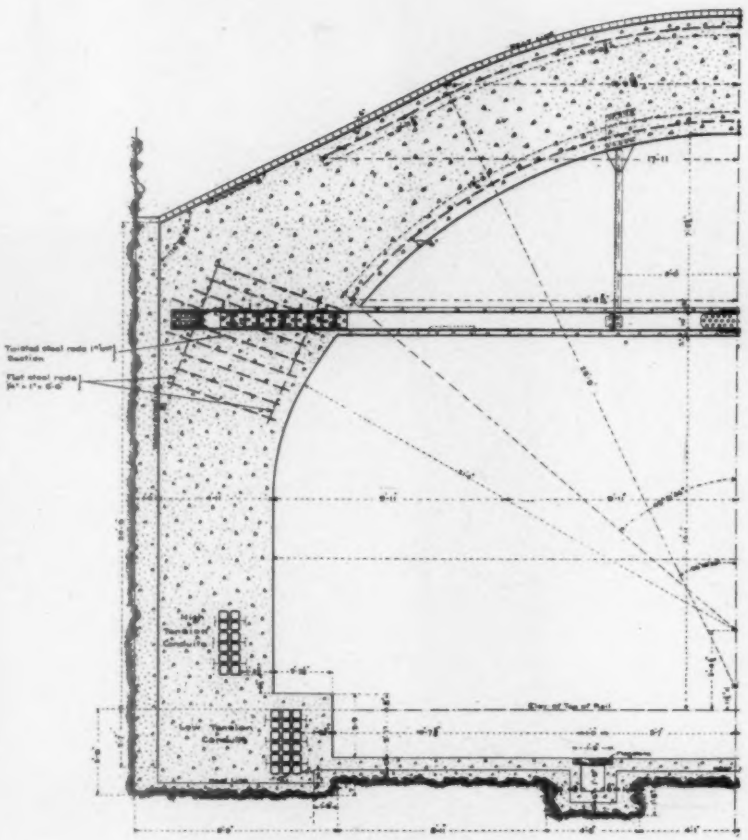
PLATE 6.



Cross-section, Bergen Hill tunnel.

View in Bergen Hill tunnel.

PLATE 7.



Cross-section, three-track tunnel.

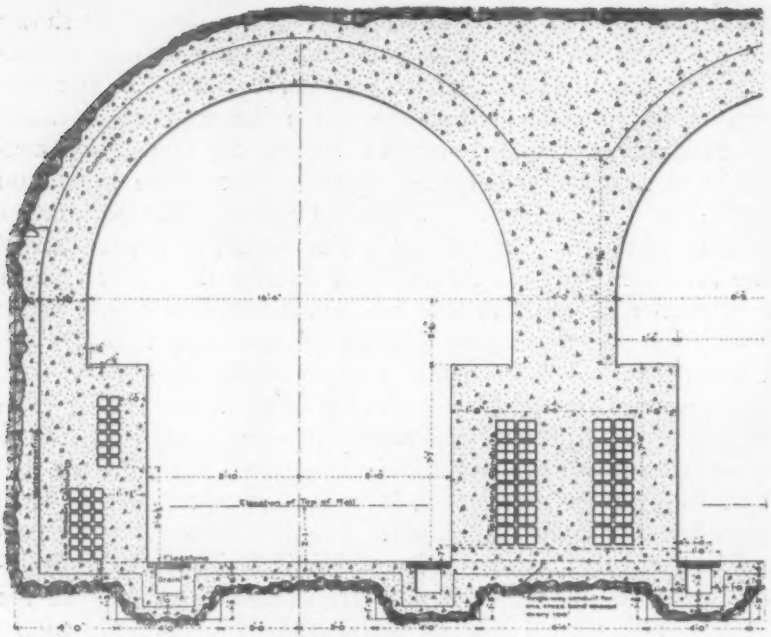
View in three-track tunnel.

completed tunnel are given on Plate 7. Near Sixth Avenue the construction under each street changes to twin-tunnel, as shown on the plate, the four single-track tunnels thus formed continuing to Second Avenue, where they curve to the left and pass diagonally under the built-up blocks, the distance between tracks of each pair diverging somewhat, so that the twin-tunnel construction ends and each tunnel passes into a separate excavation before arriving at the shafts near First Avenue. A typical cross-section of the twin tunnel and a view in the completed tunnel are given on Plate 8. At the First Avenue shafts the type of construction again changes to tube-tunnel, which continue under East River and about 2000 feet beyond, from which locality the tunnels were built in open-cutting to portals in Long Island City. The greatest depth of the bottom of the river tunnels below mean high tide is 91.3 feet. Eastward from the portals the tracks enter a large storage and car-cleaning yard. It will be noted that there are only two tunnels under the North River, while there are four under East River. The Thirty-second Street tunnels are for the use of the Pennsylvania Railroad trains arriving from the West; after discharging the passengers at the central station they continue eastward by the southerly tunnel to the yard in Long Island City, where the cars are cleaned and trains made up for the trip westward, proceeding to the station by the northerly Thirty-second Street tunnel. The two tunnels under Thirty-third Street are for the service of the Long Island Railroad.

The tunnels under Thirty-second and Thirty-third Streets pass under the existing subway line at Fourth Avenue with a clearance of some 36 feet, and the tracks in these tunnels are from 50 to 85 feet below street surface.

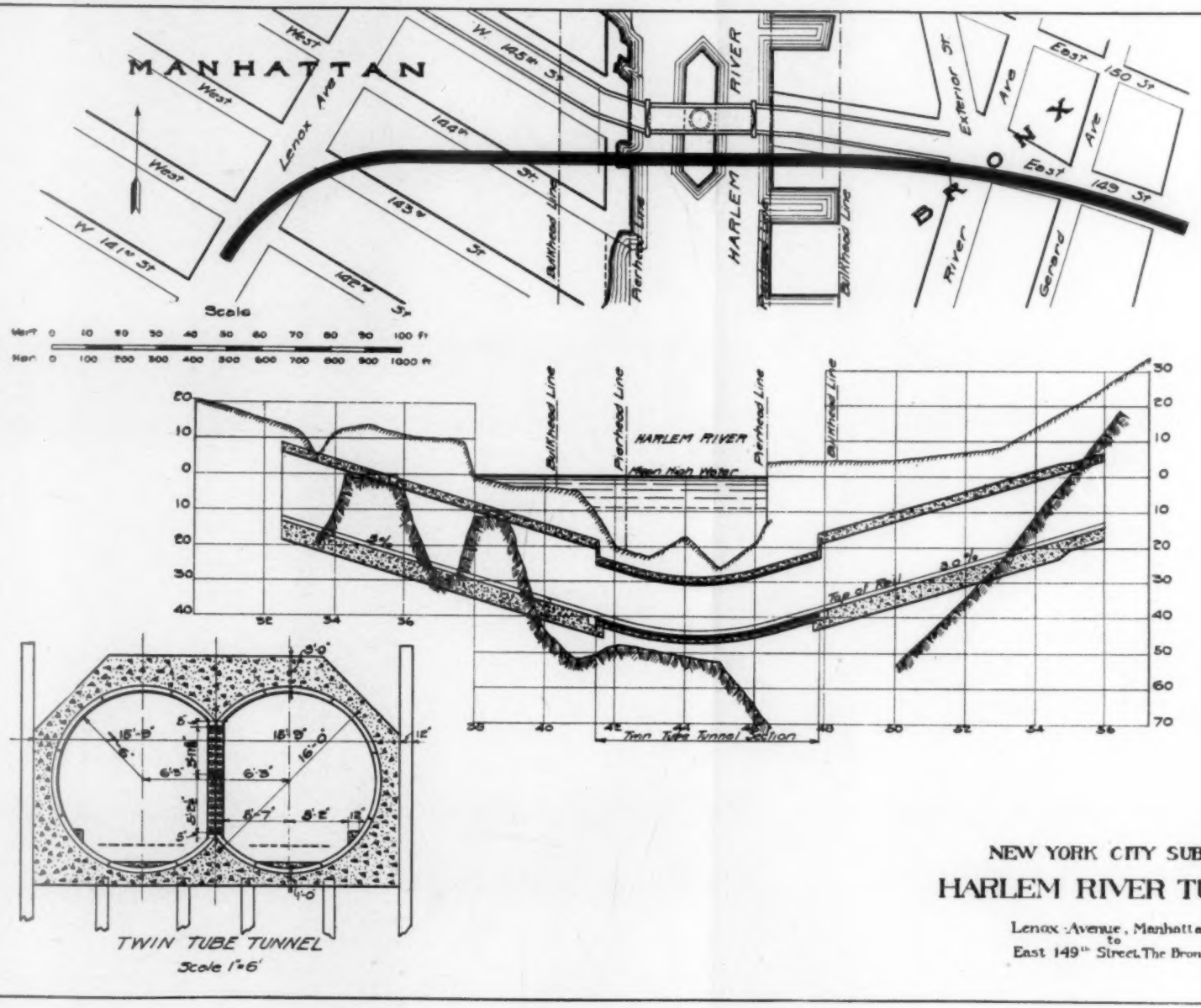
The tunnel system of the New York Terminal of the Pennsylvania Railroad, just outlined, comprises about 0.2 mile of three-track tunnels and 14.6 miles of single-track tunnels. Of the latter, 5.5 miles were shield-driven; 4.0 miles were driven by ordinary tunnelling methods as single-track tunnels; 3.6 miles by like methods for twin-tunnel construction; and 1.5 miles were built in open-cutting. All of these tunnels, except for a short distance near the westerly face of Bergen Hill, are below sea level, and this is also true as to the tracks in the station, the latter condition resulting from a franchise requirement that all

PLATE 8.



Cross-section, twin tunnel

View in twin tunnel.



NEW YORK CITY SUBWAY

HARLEM RIVER TUNNEL

Lenox Avenue, Manhattan
to
East 149th Street, The Bronx.

parts of the structure under avenues must be at least 19 feet below the street surface, in order to permit the construction of subway railroads above them.

The several systems mentioned in the foregoing include six tunnels under Hudson River, eight under East River, and one under Harlem River. The tunnels under Hudson or North and East Rivers are single-track structures and were built in greater part by the shield method and by use of compressed air. The tunnel under the Harlem River is a twin-tunnel, for two tracks, the division wall being of cast iron.

CONSTRUCTION OF RIVER TUNNELS.

It may be said in a general way that three methods have been used in building the river tunnels: the first, in point of time (if we omit the earliest attempt of Haskin, which will be referred to further on), was the pilot-tube method, which was in use for a short time in a tunnel under the Hudson, the work being finally completed by the second, or shield, method, which has been adopted in all recent work in water-bearing materials under the rivers around Manhattan, except at the Harlem River tunnel, where the third method, devised and patented by the contractor, D. D. McBean, was used with success. Although this was one of the most recent works to be executed, it seems preferable to give a brief description of it in this place before dealing with the shield method by which the other fourteen tunnels were carried out.

The City Subway Tunnel Under Harlem River.

This tunnel connects the boroughs of Manhattan and The Bronx near 145th Street, Manhattan. A map, profile and cross-section are shown in Plate 9. The portion built by the method about to be outlined was 641 feet long. The depth of water required over the tunnel for navigation purposes was only 26 feet, which corresponded closely with the actual depth of water in mid-channel.

The contractor was permitted by the War Department to close one-half of the channel at a time. The Manhattan section was first taken in hand; three stages of the construction are shown in Figs. 1, 2 and 3 of Plate 10. The first step was to dredge a channel nearly to the full depth required for the con-

PLATE 10.

FIG. 1.

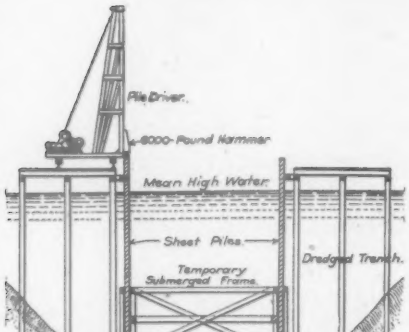


FIG. 2.

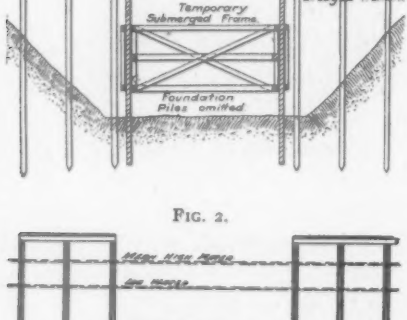


FIG. 3.

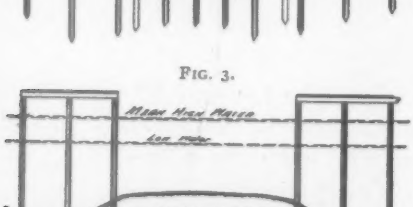


FIG. 4.

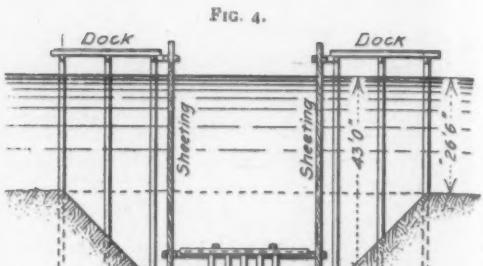


FIG. 5.

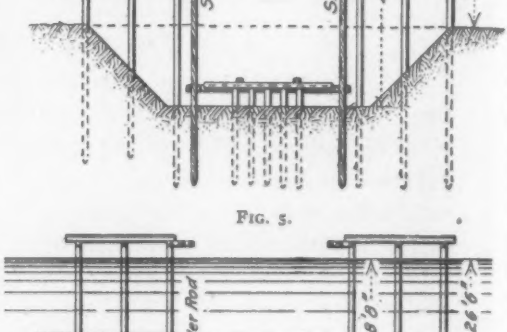


FIG. 6.

New York Subway System. Harlem River Tunnel.

struction of the tunnel; a staging or wharf on piles was then built along each side of the trench; foundation piles, spaced 6 feet 4 inches by 8 feet, were placed in the central portion of the trench and sawed off to an exact height. A strong frame, carrying guides for sheet piling, was then lowered on the piles and placed accurately. Walings attached to the wharf near the level of the deck also guided the sheet piling. The sheet piling was tongued and grooved and unusually heavy, and, being thoroughly guided while driving, was placed with great accuracy. The top of each row of sheet piling was sawed off accurately at a height slightly above that required for the finished tunnel, and a strong timber platform carrying shafts to admit men underneath was lowered on the top of the sheet piling and loaded with earth sufficiently to hold it down; the chamber underneath the platform was then completed by driving sheet piling across each end; compressed air was then put on, the water withdrawn from the chamber, and the excavation completed, the cast-iron lining built, and the enveloping concrete placed in compressed air.

In building the Bronx section the method was modified, as indicated in Figs. 4, 5 and 6 of Plate 10, by erecting the upper half of the cast-iron lining on a pontoon and placing the enveloping concrete upon it. The ends were closed by steel plate diaphragms. The pontoon was then sunk and withdrawn, the tunnel construction floating by reason of the air chamber; it was then loaded and lowered carefully on the sheet piling, forming the roof of the working chamber, and leaving only the lower half of the tunnel to be built in compressed air.

In this brief description many interesting details are necessarily unmentioned; but the work was a good example of a project carefully studied and each successive step made easy by the steps preceding.

Haskin's Tunnel Work under North River.

The first tunnel construction undertaken under either of the rivers surrounding Manhattan Island was at the New Jersey end of the north tube of the McAdoo uptown tunnels. Soon after 1870 Dewitt C. Haskin proposed to use compressed air for tunnelling in Hudson River silt, believing that by laying painted canvas against the silt to prevent air seepage through it the compressed air would support it and tunnelling would be easily done.

He was the first to use compressed air in any important tunnel, and believed the idea to be original with himself, but this appears to have been erroneous, for a compressed-air system for this purpose had been patented in England by Admiral Cockrane fifty years before. Haskin began work for two tunnels under the Hudson River in 1874 by sinking a shaft in Jersey City, but the work was held up by litigation for several years, and tunnelling in compressed air was not begun until 1879. Unfortunately, Haskin's method was not practicable in the soft silt or mud of the bed of Hudson River, and on one occasion, after several accidents of less importance, an inrush of mud occurred and several lives were lost. His superintendent, John Anderson, then devised the so-called pilot-tube method, which consisted in first driving a small tunnel about 6 feet in diameter along the axis of the larger one; this pilot tunnel was lined with plates bolted together at the edges, and was built to a length of 50 or 60 feet. The excavation was then carefully enlarged around the rear end of the pilot tube to the full size desired and lined with thin plates, which were supported by radial struts from the pilot tube. After thus enlarging the excavation for a short distance the brick tunnel lining was built in and the rear plates of the pilot tunnel were removed and carried through the tube and again built in at its front end. After many vicissitudes Haskin was finally obliged to stop, in 1888, after having built the north tube for a length of about 2000 feet and the south tube about 570 feet from the New Jersey side. He had also sunk a shaft in Morton Street, Manhattan, near the river bulkhead, and had built the north tunnel for a distance of 160 feet. The distance between the shafts was about 5700 feet, so that there remained to be built about 3500 feet in the north tunnel and about 5100 feet in the south tunnel. In the following year the enterprise was taken up by English capitalists and contractors and work resumed by the shield method; with the single exception before noted, this method has been used for all tunnelling in soft ground under both rivers since that time.

DEVELOPMENT OF SHIELD METHOD.

The development of the shield method of tunnelling has covered a period of nearly 100 years, but it is only within a comparatively recent period that the method has come into frequent

PLATE II.

FIG. 1.

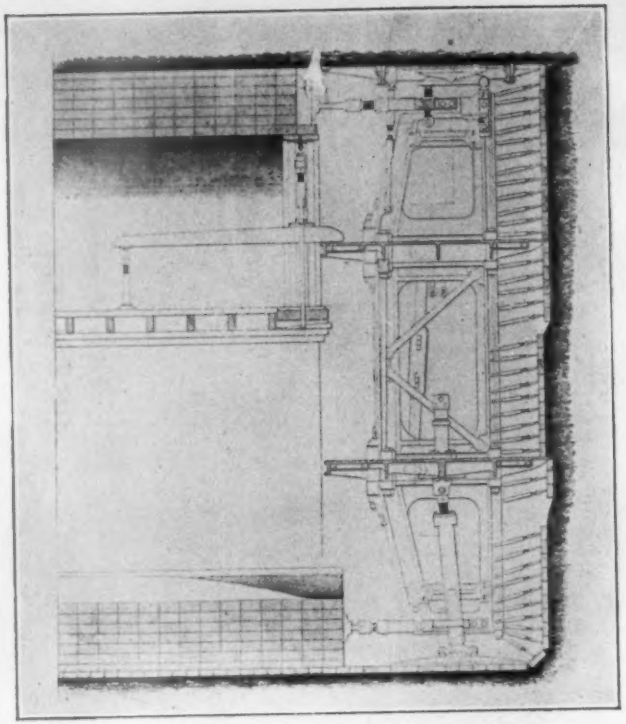


FIG. 2.

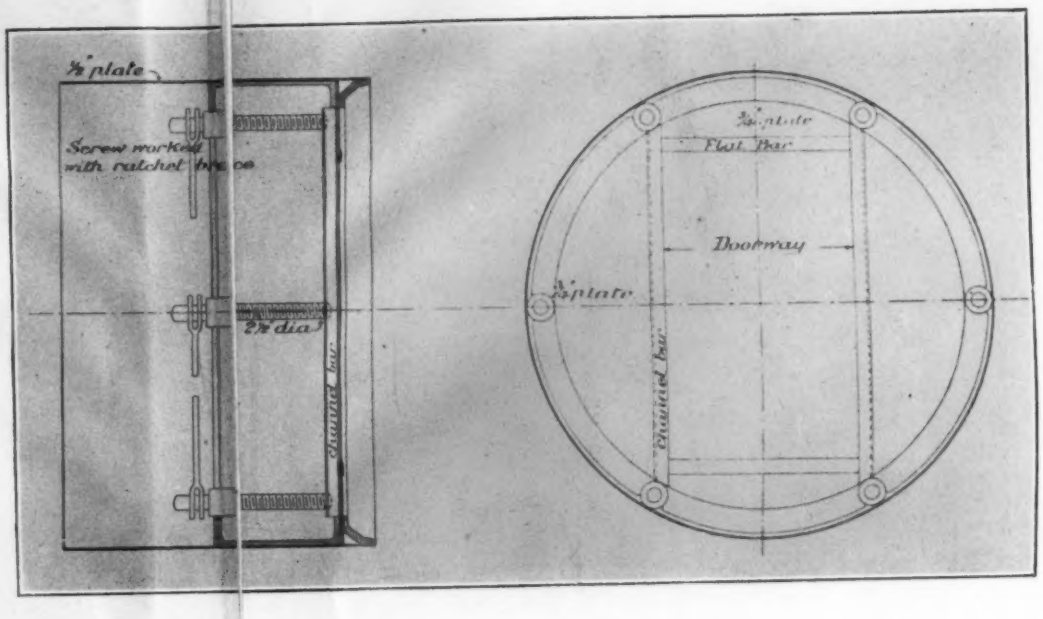


FIG. 3.

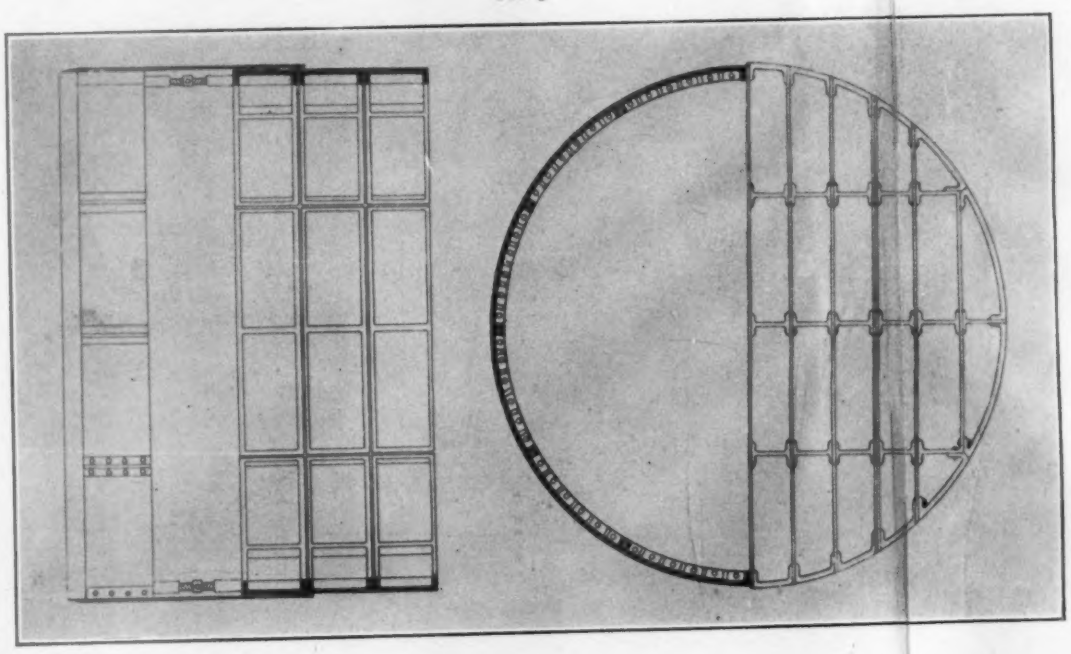
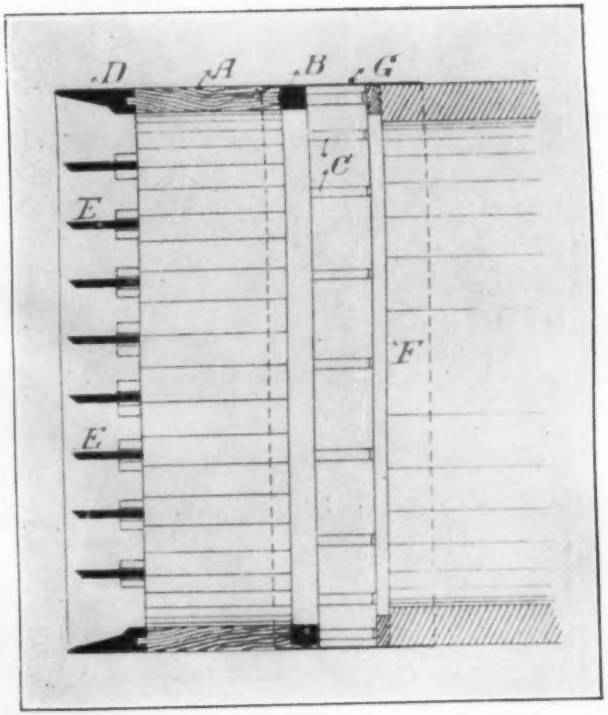


FIG. 4.



use. The first proposal for shield tunnelling, described in a British patent issued to Marc Isambard Brunel in 1818, included the essential features of modern shield tunnelling—a movable structure in advance of the completed tunnel, affording protection to the men at the face of the heading and provision for building the tunnel in short lengths inside the rear portion of the movable structure. Brunel's shield (Fig. 1, Plate 11) was composed of a large number of sections separately controlled. With such devices Brunel completed a tunnel under the Thames at London between the years 1828 and 1843. While the principles involved were much the same as in the shield of the modern type, there was little other resemblance.

The next important development was covered by a British patent issued to P. W. Barlow in 1864. The shield was to be a single structure and was essentially a cylinder a little larger in diameter than the tunnel (Fig. 2, Plate 11). As in Brunel's design, the tunnel was to be built up in short lengths within the rear portion, or tail, of the shield; the successive tunnel lengths were to be short, cylindrical iron rings. The shield was to be forced forward by means of screws. The use of hydraulic presses instead of screws to force the shield forward appears to have been first suggested by R. Morton, of Stockton-on-Tees, and is mentioned in a provisional patent issued to him in 1866. The use of the cast-iron cylindrical rings formed of segments, the segments and rings bolted together through inside flanges, is clearly defined in Morton's patent; the front of the shield, however, was to be (quoting the patent) "sharp or pointed like a wedge," an idea which has not yet been carried into practice.

Neither Barlow's nor Morton's shield was put into use, but a shield of similar type was designed, built, and used by J. H. Greathead in the construction of the Tower Subway under the Thames in 1869 (Fig. 3, Plate 11). This was the first tunnel built of cast iron, and has been the model for nearly all shield-driven tunnels built since that time.

In the meantime the subject had received attention on this side of the Atlantic, and in 1869 a shield designed by A. E. Beach was put into use and a short piece of tunnel built under Broadway, New York. In Beach's shield (Fig. 4, Plate 11), hydraulic presses were used for the first time to force the shield forward, antedating the use of hydraulic presses by Greathead in the con-

struction of the City & South London Railway tunnel under the Thames by several years. There has been much dispute in regard to the respective claims made in behalf of Greathead and Beach as to priority in design and actual use of the modern tunnel

PLATE 12.

Beach's shield.
Built 1869. Photographed 1912.

shield; there is hardly room for question, however, that modern shield tunnelling owes more to Greathead than to anyone else.

Beach's Broadway tunnel had been nearly forgotten until within the last year, when it was uncovered and removed in the building of a rapid transit subway. The shield was also found,

the wood nearly all rotted away, but the metal portions and the hydraulic presses still intact (Plate 12).

The history of the development of the shield system of tunnelling during the ensuing thirty years need not be followed in detail. It will suffice for our present purpose to point out more definitely than I have done hitherto the principal features of the shield-driven tunnels as usually constructed and the essential parts of the shield by means of which they are built.

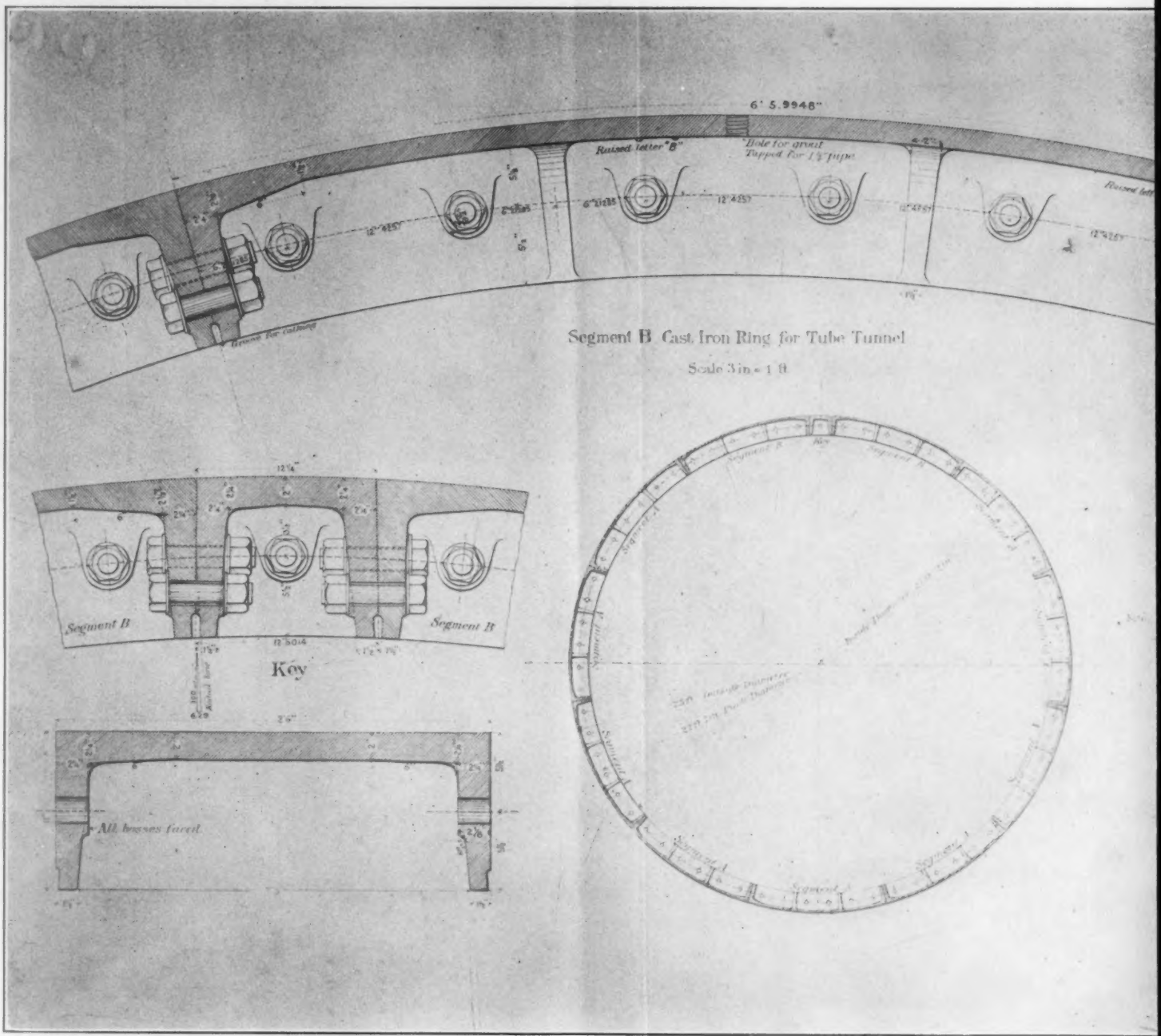
THE CAST-IRON TUBE.

The first stage in the construction of such a tunnel is to build the tube; this usually consists of cast-iron segments built into rings. Plate 13 shows the interior of such a tube, and Plate 14 shows details of the cast segments. The segments are 6 to 7 feet long, with radial joints, except a short closing segment or key in which the taper is reversed to facilitate building. Usually all meeting faces of the segments, including the joints between successive rings, are machined to true surfaces. The width of the rings varies in different tunnels from 18 to 30 inches. The segments and the rings are connected by bolts through inside flanges. Taper rings having a greater width on one side are used where it is desired to correct alignment or grade, or to pass along curves.

In the process of moulding a segment a rebate is formed around the inner edge of the side of the flange, resulting in a narrow but relatively deep groove after the segments are bolted together in the tunnel. In such material as the North River silt, which is nearly water-tight, a water-tight joint is secured by caulking ordinary rust-joint materials into the grooves. Where the material surrounding the tube is freely water-bearing the water filtering through the joints washes out the rusting ingredient before it has time to act, and rust-joint work is unsatisfactory. Better results are obtained by caulking lead into the joint, usually in the form of a rod or wire. After caulking the rod or wire into the bottom of the groove the remainder of the groove is filled with cement mortar.

The bolt holes in the segments are cored considerably larger than the bolts to facilitate erection. They are usually made water-tight by grummets of hemp saturated with red lead and oil, or by winding the bolts with saturated hemp strand. These

PLATE 13.



Details of cast-iron linings.

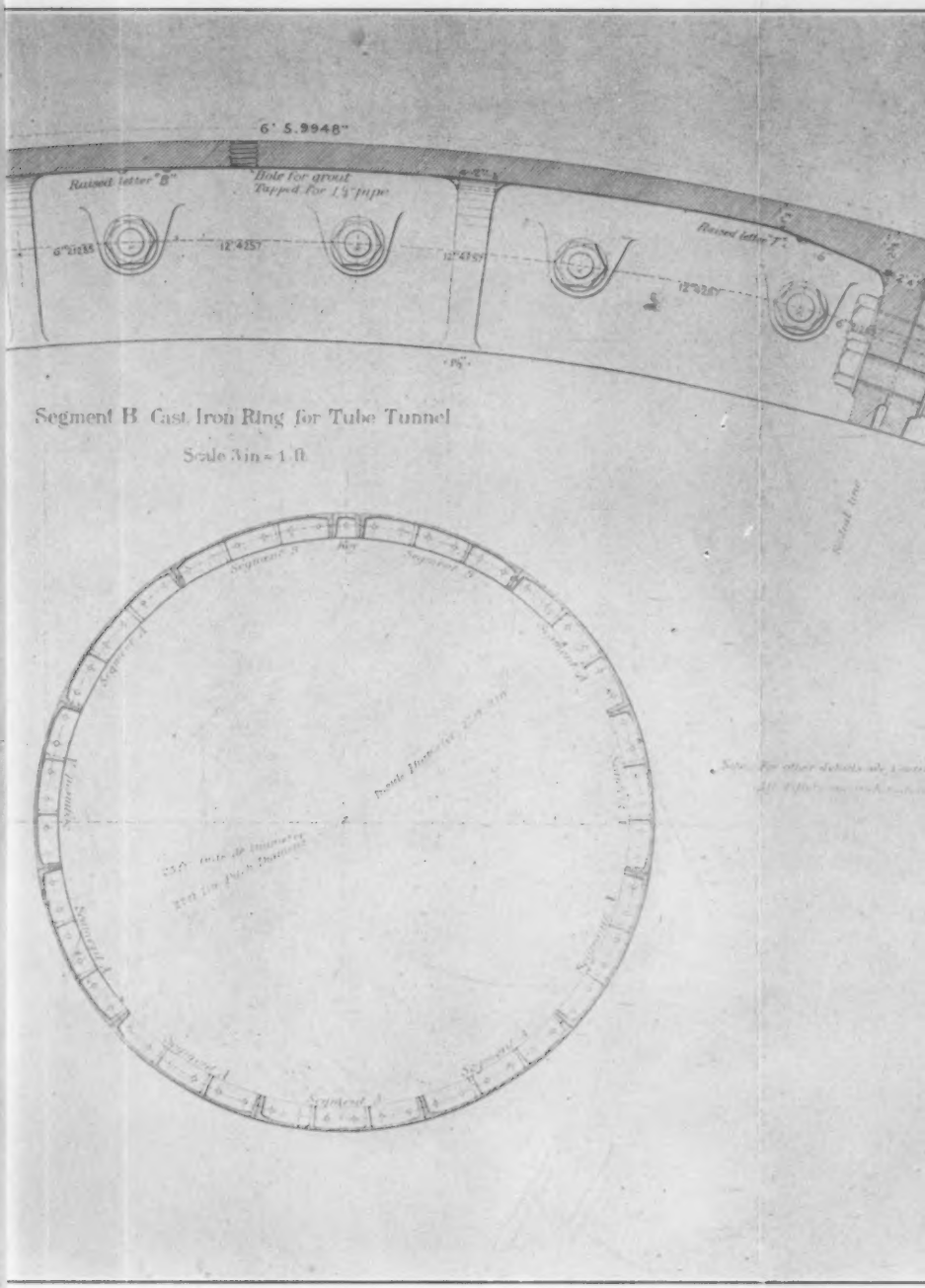
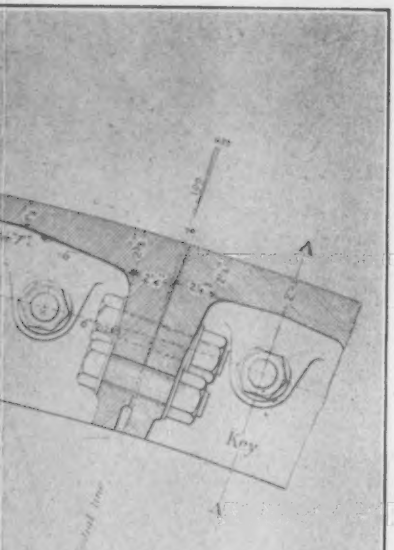


PLATE 13.

Details of cast-iron linings.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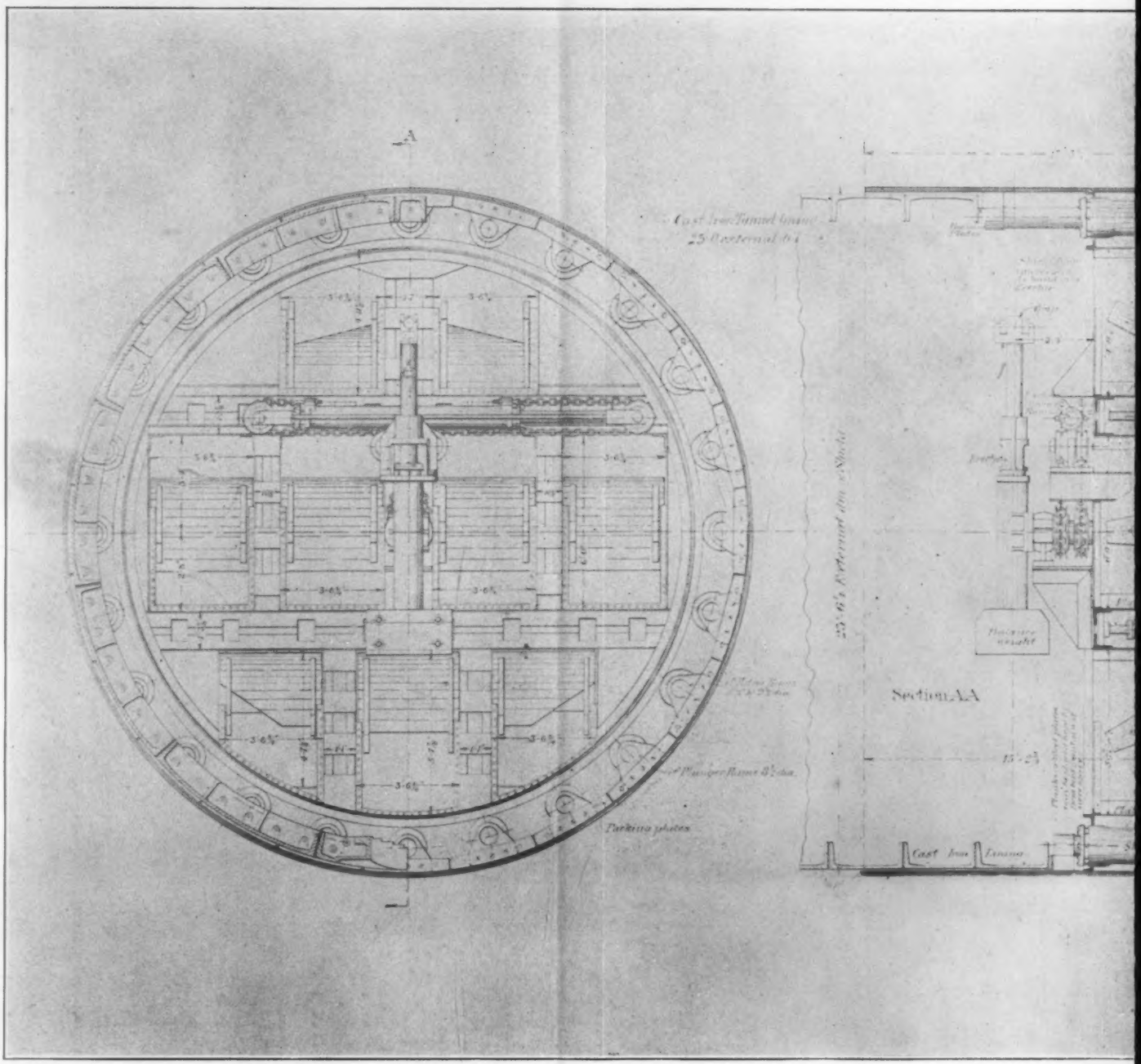
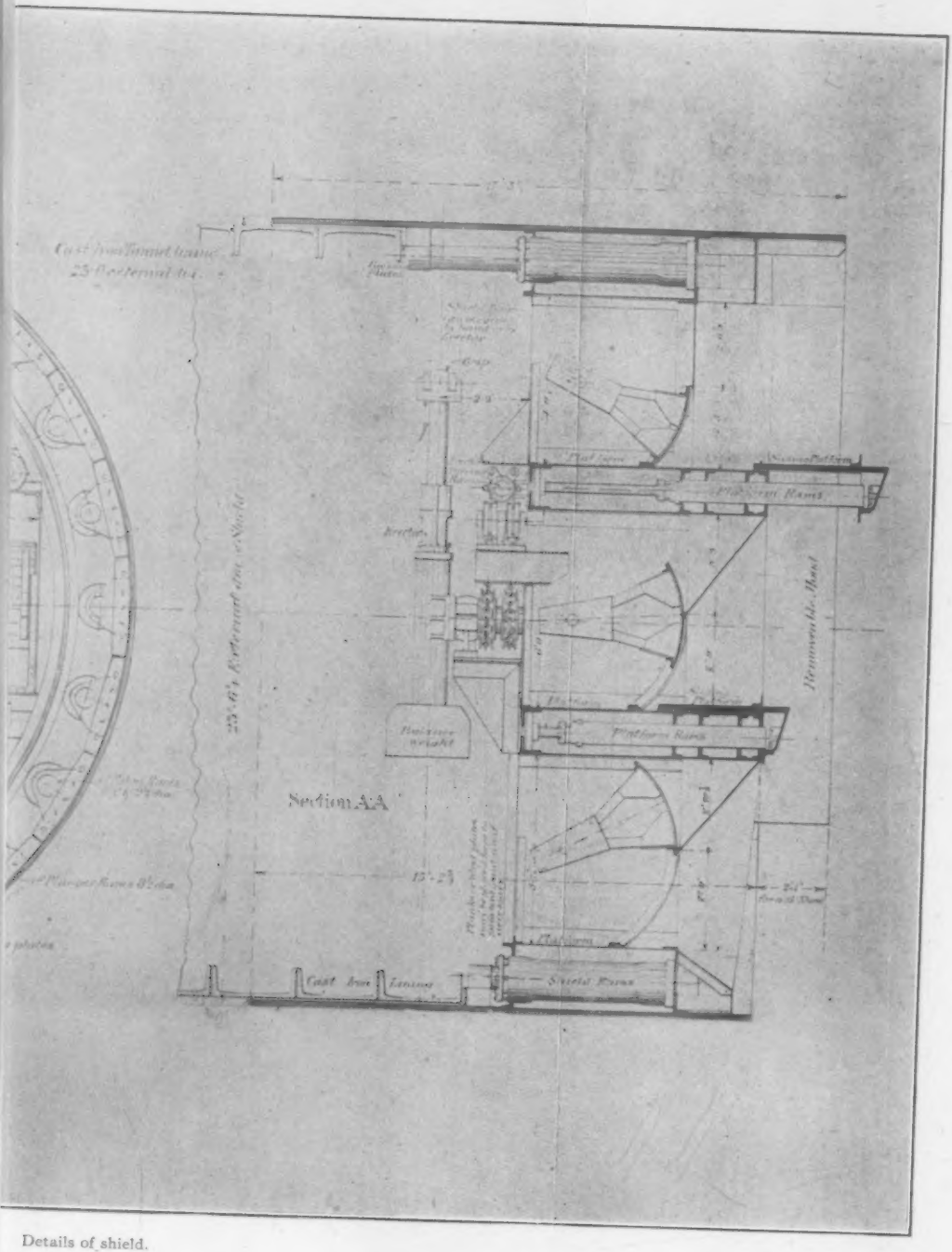


Details of shield.

PLATE 15.



Details of shield.

wrappings or grummets are placed between washers and the faces of the castings and afterward compressed when the bolts are tightened up.

It is probably not realized to what extent tunnel construction of this form has been carried out in connection with the tunnel systems referred to, the actual total being nearly 17 miles.

THE MODERN SHIELD.

A shield may be defined as a short, movable length of tunnel, affording protection for excavating in the advancing face and for erecting successive rings of tunnel lining within the rear portion or tail. In the North River silt the shield could be pushed along without excavating in front, but in firmer materials, such as clay, sand, gravel, and rock, the shield must afford facilities for excavation before the shield can be advanced. The shield used in the Pennsylvania Railroad tunnels under North River is shown in sectional view on Plate 15. Front and rear views of a shield used in one of the Pennsylvania Railroad tunnels under East River are shown on Plate 16.

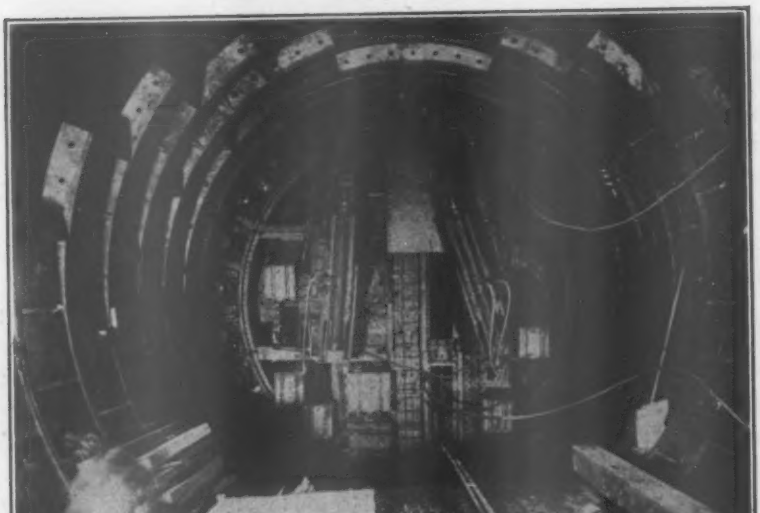
The structural portion of the shield may be considered as made up of three sections, as follows:

First.—The cutting edge, which for use in firm materials must be made very massive, as illustrated in the East River shields on Plate 16. In this shield the cutting edge was of heavy steel castings strongly connected with each other and with the cylindrical shell of the shield. This ring of heavy castings was continuous around the circumference of the shield, the projecting part shown in the upper portion, intended for use in sand, being temporarily attached to the true cutting edge. Such a heavy cutting edge was not needed in the silt of the North River, and the sectional view, Plate 15, shows a lighter construction.

Second.—The central portion or body of the shield carries an interior shell, concentric with the outer one, the two being connected by diaphragms or ribs forming longitudinal pockets, within which are placed the hydraulic jacks for pushing the shield forward. The circular girder formed by the two concentric and connected shells is further strengthened by one or more transverse plates or diaphragms connected all around with the circular girder, and (in the shield shown on Plate 16) by two horizontal floors and two vertical partitions, connected with the circular

PLATE 16.

Front of shield.



Rear of shield.

girder, the transverse diaphragm, and with each other. The number of floors and vertical partitions varies according to the dimensions of the shield. The body of the shield carries various devices for maintaining the face in soft ground, erectors for building the successive rings of the tube, etc. The transverse diaphragms has openings for passing men or materials. In the Hudson River shield shown on Plate 15 these openings were closed by swinging or "Taintor" gates. The hydraulic jacks take bearing against the face of the ring last erected (see Plate 16). After the shield has been pushed forward far enough to permit the erection of another ring of the tube, or, technically speaking, when the "shove" is completed, the jacks are closed, or "drawn home," leaving a space of sufficient width for the new ring.

Third.—The tail of the shield has no interior bracing. When the shield is in position for the erection of a new ring the tail should overlap the second ring back, as shown on Plate 16, in order to permit the removal of any broken segment in the ring last erected.

The resistance to the forward movement of the shield may be very great, and the equipment of hydraulic jacks in the New York tunnel shields could exert a pressure of 2000 to 6000 tons. When the material was rock, blasting was often carried on immediately in front of, and almost in contact with, the shield. Under such severe treatment some of the shields were much damaged.

The larger diameter of the shield as compared with that of the tunnel causes an annular void to be left immediately behind the shield sufficient to cause settlement at the surface of the ground, and, where the shield is driven under city streets, may cause injury to adjacent buildings. This result can usually be prevented, or at least minimized to a large extent, by forcing grout outside the lining through holes in the segments provided for this purpose, each hole being closed by a screw plug.

SHIELD TUNNELLING METHOD APPLIED IN NORTH RIVER.

The resumption of work in 1889 in the tunnels under North River begun by Dewitt C. Haskin, and the use of the shield method in continuing it, have been mentioned. This resumption related only to the north tube. The shield was of the Greathead

type, and was built in Scotland; the tunnel work was under the immediate superintendency of E. W. Moir, then a young man beginning a career in tunnelling operations which has covered a large amount and wide range of difficult work. In this shield Greathead's earlier design was modified to better adapt it to the soft, flowing silt which forms the bed of North River, producing an effective tool with which a length of about 1900 feet of tunnel was built without serious difficulty of any kind; the work was then suspended for financial reasons and not again resumed until 1902, when it was taken up by the New York & New Jersey Railroad Company, the predecessor of the Hudson & Manhattan Railroad Company, under the general management of W. G. McAdoo, with Charles M. Jacobs as chief engineer. Moir's shield, after submergence for twelve years, was found to be in excellent condition, requiring only cleaning the machinery and slight repairs, and the river tunnel was completed with it.

THE MCADOO TUNNELS.

The problem of tunnelling through Hudson River silt had been substantially solved by Moir, but a new problem awaited, for soon after work was resumed in 1902 rock was encountered in the bottom of the excavation and continued for several hundred feet, and at its highest point was 15 feet above the bottom of the tunnel, giving nearly a full face of rock. While the tunnel was in silt but little excavation was necessary, and usually this could be made without going in front of the shield by opening a door or slide in the face of the shield and permitting the material to enter the tunnel; but when rock was met it was necessary to work in front of the shield in order to drill, blast, and remove it. The soft silt required support by timbering, which was usually practicable, but in one place where the silt was in a semi-fluid state this was found insufficient, and a novel scheme was tried—that of hardening the clay by heat. Blowpipes fed with kerosene were applied for eight hours, after which the clay was found solidified sufficiently to permit the work to be continued. After passing the rock, sand was encountered, and this continued until meeting the old tunnel extending westward from Haskin's Morton Street shaft. The work since resumption had occupied 505 days, during which 1625 feet of tube tunnel were built, an average of 3.2 feet per day. Has-

kin's bulkhead across his Manhattan heading was broken through March 11, 1904, thus completing the first tunnel under the Hudson River, about thirty years after it was begun.

The original project of Haskin was intended to provide for the passage of ordinary trains; the brick tunnel was 18 feet high inside and 16 feet wide, the cross-section being elliptical. The circular cast-iron tunnel subsequently built by Moir had a diameter of about 18 feet inside the flanges, giving an exterior diameter of about 19 feet 5 inches (Fig. 5, Plate 3), probably with the same traffic in view. When the New York & New Jersey Railroad Company took up the work, the Moir shield being still in place and usable, the north tunnel was completed with but slight change in diameters. This company, however, did not contemplate a tunnel system for ordinary railroad service, but for suburban trains with smaller cars, and therefore adopted smaller dimensions for the three remaining tunnels, reducing the exterior diameter to 16 feet 7 inches and the inside diameter, clear of the flanges, to 15 feet 2½ inches.[2] The exterior diameter of the new shields was 17 feet, a material reduction from the Moir shield, greatly facilitating pushing the shield through the North River mud, and while it became advisable, from time to time, to admit a small proportion of the material from the front of the shield into the tunnel, through the doors in the diaphragms of the shield, this only averaged about 5 per cent. of the amount displaced. The greatest caution was required in admitting this material on account of its semi-fluid character. When working alongside the coal wharf of the Delaware, Lackawanna & Western Railroad, where special care was needed to avoid injuring the wharf, the chief engineer issued stringent orders that the doors should be kept closed while the shield was moving forward. On one occasion a night superintendent, finding the shields moving very slowly, disobeyed orders and opened the door. The mud being compact and solidified required at first to be dragged through the opening. All went well for about half an hour, when suddenly a jet of silt of the cross-section of the opening shot through and buried one of the men, the remainder of the force escaping through the airlock some distance back in the tunnel. Within a short time the tunnel became solidly filled

[2] For details of dimensions and weights of cast-iron lining see table on page 384.

PLATE 17.

Hudson & Manhattan Railroad. McAdoo tunnels. Morton Street curve.

with mud back to the bulkhead in which the airlocks were placed. In order to recover the tunnel, the bed of the river over the end of the tunnel and just ahead of it was covered with a large canvas of double thickness. A valve at the outer end of the pipe which extended through the airlock bulkhead was then opened and the mud shot out a distance of 40 feet, and cars were filled with it for eight days; as mud was thus withdrawn through the bulkhead the tunnel between the bulkhead and the shield was kept filled by the mud entering through the open door of the shield, gradually forming a depression in the river bed, which the canvas followed until it finally reached the door and blocked it, after which the men worked their way into the tunnel, compressed air was again put on, and in nine days more the shield was reached and the door closed.

As experience was gained mishaps became infrequent and progress through the mud became rapid. In one week 346 lineal feet of tunnel were built, and about 70 lineal feet were built in one day of 24 hours. There were difficulties when rock was met and also when passing through sand, similar to those to be referred to in connection with the tunnels of the Pennsylvania Railroad.

In driving the shields landward from the Morton Street shaft toward Sixth Avenue it was necessary to build some sharp curves; one of these of 150 feet radius is shown on Plate 17.

Typical cross-sections are shown on Plate 3. All of the tunnels except the north uptown tunnel are of the standard section shown in Fig. 4. The track is of the ballasted type, laid on a concrete floor, the concrete being extended far enough up the sides of the tube to enclose the ducts for the electric cables required for operating the railroad. The north uptown tunnel was built of larger section, as before mentioned, but the interior section brought to standard dimensions by an interior lining of concrete as shown in Fig. 5.

The uptown tunnels from Hoboken were opened for traffic to Nineteenth Street and Sixth Avenue in February, 1908, and to Thirty-third Street in November, 1910. The downtown tunnels were opened from Church Street to the Pennsylvania Railroad station in Jersey City and successive portions of lines paralleling the river were put in service at various times in 1909 and 1910.

Hudson & Manhattan Railroad. McAdoo tunnels. Morton Street curve.

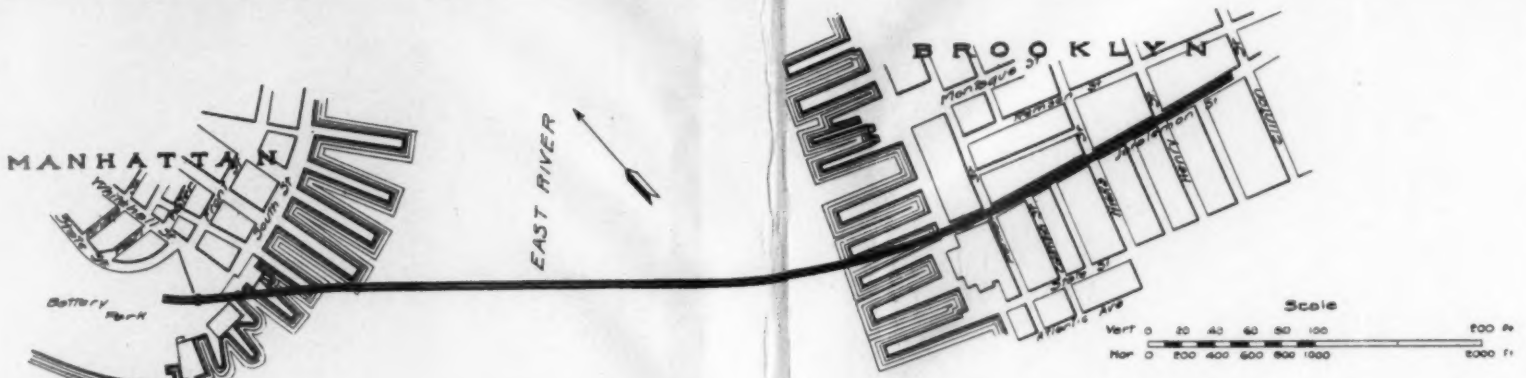
THE NEW YORK CITY SUBWAY TUNNELS UNDER EAST RIVER BETWEEN MANHATTAN AND BROOKLYN.

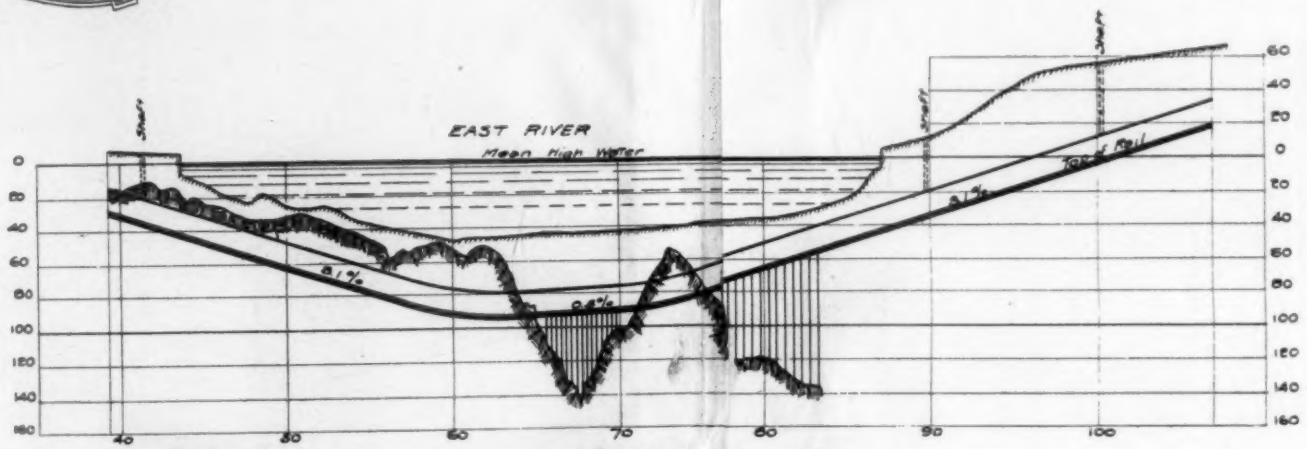
The portions of the subway system here considered comprise two cast-iron tubes under East River from a point near South Ferry in Manhattan to the foot of Joralemon Street in Brooklyn, a distance of 4372 feet, and their extensions landward for a distance of 440 feet in Manhattan and 1978 feet in Brooklyn, making a total distance of 6790 feet, or 13,580 lineal feet of tube tunnel. A map, profile, and typical cross-section are shown on Plate 18. For the greater portion of their length under the river the tubes are 16 feet 8½ inches in diameter outside and 15 feet 5½ inches inside the flanges, and are of two types, one weighing 4545 pounds per lineal feet of tunnel, the other 5133 pounds. Somewhat heavier metal is used under the river bulkheads. In rock a lighter section is used, weighing 3992 pounds per lineal feet of tunnel, and is intended mainly for waterproofing.[3] In Brooklyn the same lighter section is used in the tubes above tide level. The tunnels were begun in 1903 and completed in 1907.

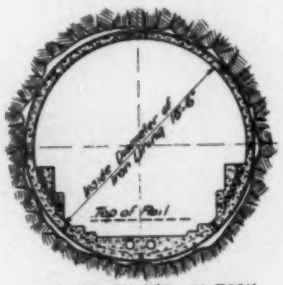
Tunnelling in the rock from the Manhattan side presented no marked features, but the earth presented two troublesome types: a rather coarse sand on the Brooklyn side and an extremely fine quicksand in the middle of the river. The difficulties met in passing through the quicksand were duplicated in the construction of the Pennsylvania Railroad tunnels, and will be described more fully in connection with that work. On the Manhattan side the tunnels in rock were built in air of normal pressure until the river front was passed, when airlock bulkheads were built across the tunnels and the compressed air was put on. Toward the middle of the river, near the point where the rock surface was broken through, shields were erected and tunnelling was continued out of the rock and into the earth to the points of junction with the Brooklyn shields.

On the Brooklyn side two shafts, one for each tube, were sunk at the points where the tubes rise above tide level, about 2000 feet eastward from the water front; shields were erected and started eastward in the dry headings, after which two other

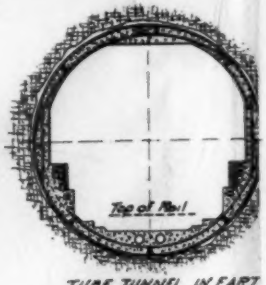
[3] For details of dimensions and weights of cast-iron lining see table on page 384.







TUBE TUNNEL IN ROCK
Scale 1'-6'

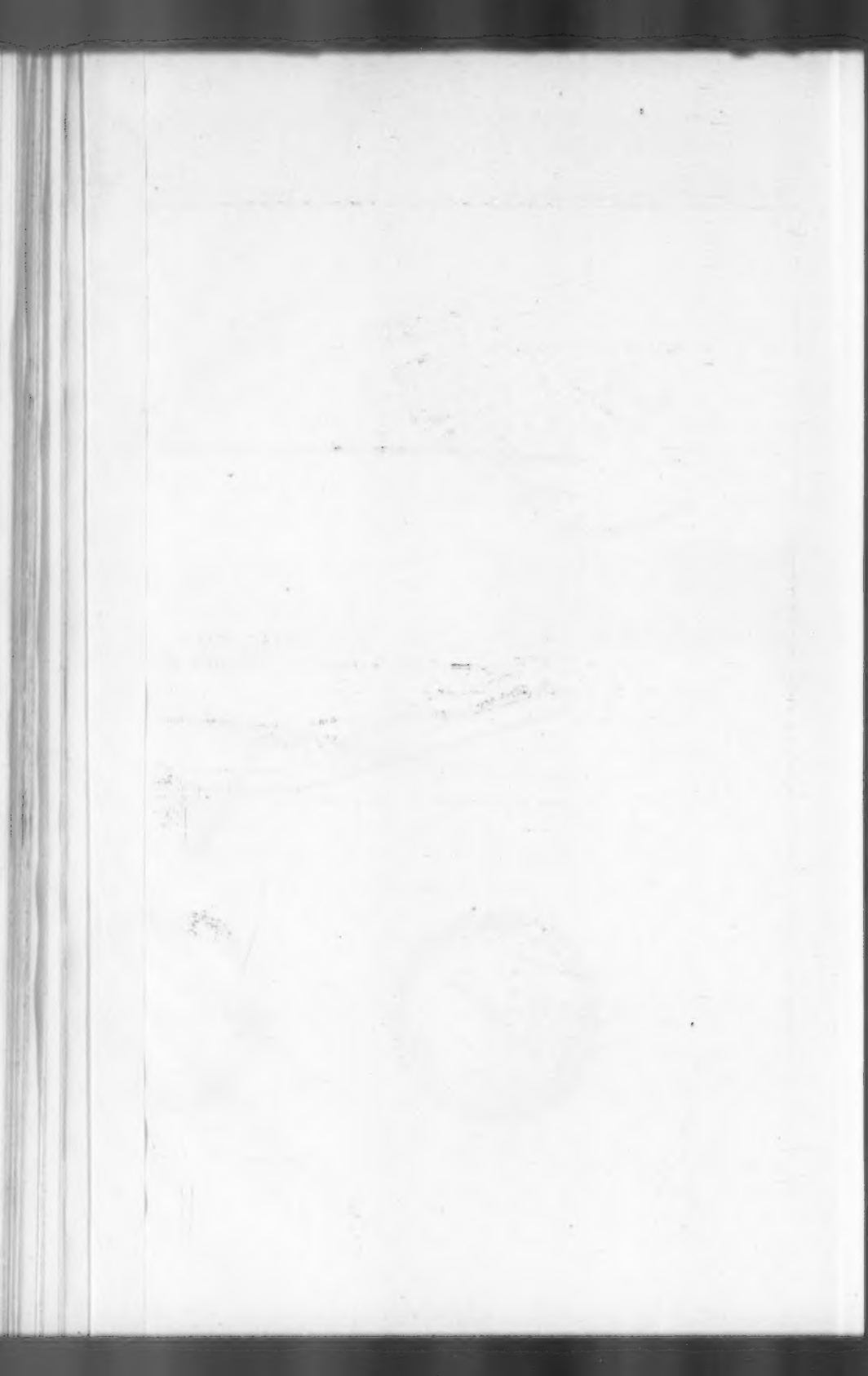


TUBE TUNNEL IN EARTH
Scale 1'-6'

NEW YORK CITY SUBWAY

EAST RIVER TUNNELS

Battery Park, Manhattan
to
Joralemon St., Brooklyn



shields were erected in the same shafts and driven westward to the points of junction with the Manhattan shields.

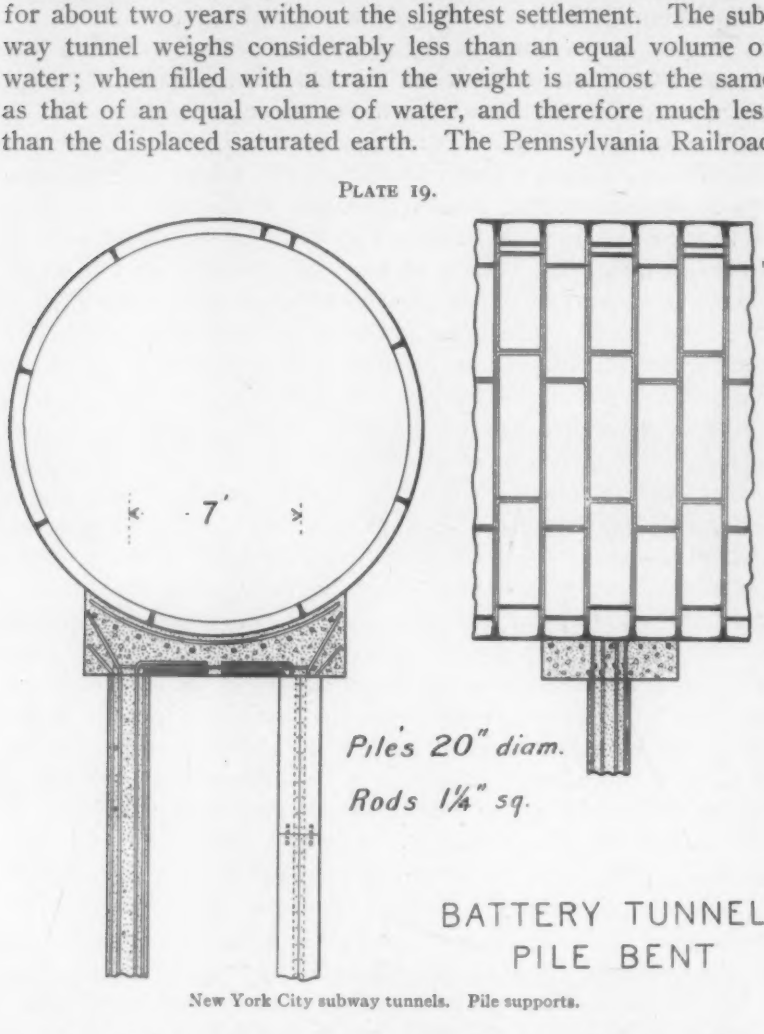
Tunnelling in quicksand was a new problem met here and in the Pennsylvania Railroad tunnels almost simultaneously. In places the shield settled below the proper grade line, and in some places the changes in grade were too sharp for convenient operation of trains. The diameter of the tunnel gave so little leeway for trains that it was necessary to depress the bottom or to raise the roof of the tunnel so as to permit easier vertical curves in laying the track. In quicksand these were extremely hazardous operations unless done with the greatest care and skill. The lowering of the bottom of the tunnel was accomplished by first raising the air pressure enough to dry the underlying material when exposed and successively removing the cast-iron segments in the lower half of the tube, replacing them with new segments curved to an elliptical form so as to give a greater vertical diameter and therefore a lower bottom. This was a less hazardous operation than to raise the roof, and was the method generally adopted in the reconstruction. For a short distance in each tunnel the roof was actually raised by powerful hydraulic jacks sufficiently to permit the construction of a new masonry roof with a greater vertical clearance.

During the construction of these tunnels in the section where quicksand was encountered sensational articles appeared in the newspapers alleging the impossibility of maintaining the tunnels in position under traffic, and it is to be regretted that this alarm was promoted by a few engineers. It was finally decided, although believed unnecessary by the city's engineers, to support the tunnels in quicksand by means of concrete columns or piles. In order to place them the bottom segments of the tunnels were removed at intervals of 30 to 50 feet and the piles sunk by use of the hydraulic jet to harder materials at depths ranging from 5 to 75 feet. They were placed in pairs 7 feet apart transversely to the tunnel and their tops connected after sinking by reinforced concrete cradles conforming to the transverse outline of the tunnel. The cast-iron segments were then replaced, and the tunnel rested, more or less completely, on the cradles. About 1200 lineal feet of each tunnel were thus underpinned (Plate 19).

Since this work was done, the Pennsylvania Railroad tunnels under the East River, passing through similar material and

unsupported except by the earth itself, have been in operation for about two years without the slightest settlement. The subway tunnel weighs considerably less than an equal volume of water; when filled with a train the weight is almost the same as that of an equal volume of water, and therefore much less than the displaced saturated earth. The Pennsylvania Railroad

PLATE 19.



New York City subway tunnels. Pile supports.

tunnels, with heavier construction, weigh somewhat more per lineal foot when loaded with a train than the displaced earth, and the tendency to settle would seem to be greater. It is well known that quicksand, when confined, will carry heavy loads without yielding, and, in fact, some of the high buildings in New York rest upon material undistinguishable from the river

quicksand. In view of all this there is no room for doubt that the opinion of the city's engineers was correct.

The cast-iron lining in the city's tunnels was of lighter section than in the McAdoo tunnels, the latter being about 25 per cent. heavier. This is compensated for by strongly reinforcing the concrete lining where the tunnel is in earth under the river, where the pressure upon it is the greatest. The tunnels were opened for traffic in January, 1908.

PENNSYLVANIA RAILROAD TUNNELS UNDER NORTH RIVER.

A map, profile, and typical cross-section of these tunnels are shown on Plate 20.

For some distance from the shafts on both sides of the river the tunnels are in rock and were driven in normal air by ordinary methods. When the excavation in each tunnel had arrived near the point where the tunnel would pass out of rock into earth it was enlarged sufficiently to permit the erection of the shield; there were four shields for the North River tunnels, one in each tunnel on each side of the river (Plate 15). They were designed under the direction of Charles M. Jacobs, chief engineer of the North River Division. As they were to be driven through silt they were somewhat less massive and powerful than those for East River, where the materials ranged from quicksand to gravel, boulders, and rock. Still, the large tunnel dimensions adopted by the railroad company, the exterior diameter of the tube being 23 feet,[4] resulted in a very heavy shield, weighing, with all its accessories, 193 tons. To force it forward in the tunnel 24 hydraulic jacks were provided, capable of exerting a push of about 3300 tons.

After building the shield a concrete bulkhead was built across the tunnel behind it, containing three airlocks, two near the floor level through which the excavated materials were passed out and cast-iron tunnel lining, cement, and other material for construction were passed in. A third airlock was placed in the upper portion of the bulkhead for the use of the working force entering or leaving the tunnel. Each airlock was a steel tube about 7 feet in diameter and 20 to 25 feet long, with a door

[4] For details of dimensions and weights of the cast-iron lining see table on page 384.

at each end opening toward the tunnel and air tight when closed. The bulkhead also contained smaller airlocks for passing pipe and similar materials into or out of the tunnel, pipe for compressed air, for water under pressure to operate the shield jacks, electric light wires, etc.

After the bulkhead was completed compressed air was admitted to the tunnel and the advance of the tunnel excavation continued. The passing from rock to earth was a critical stage, when the danger of an inrush of earth was particularly great.

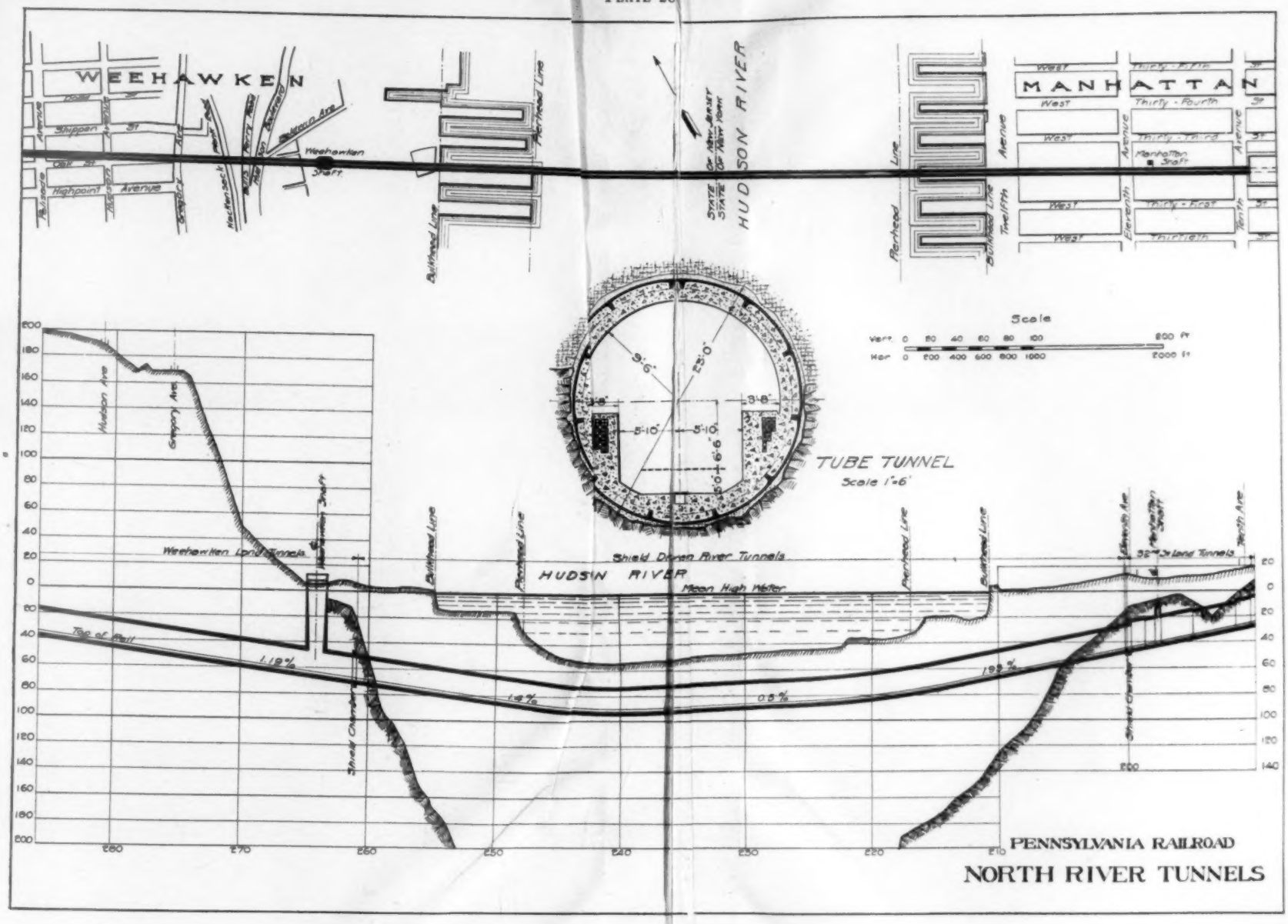
The first application of compressed air in these tunnels was in June, 1905. Prior to this the north tunnel of the uptown McAdoo tunnels had been completed under the river and a trained force was available for the Pennsylvania tunnels.

After passing out of rock and entering silt or mud it was seldom necessary to go in front of the shields. The hydraulic jacks could exert sufficient pressure to force the shield through the mud, but it was found impossible to keep the shield down to grade unless a portion of the mud in front was received into the tunnel. The portion required was, on an average, about 33 per cent. The principal office of the diaphragm, therefore, aside from the important one of stiffening the cylinder of the shield, was to furnish suitable openings for the admission of mud and sure means of closing them when desired.

Each shield was provided with one erector. It rotated on an axis on the centre line of the shield, in a plane normal to the tunnel and corresponding with the middle of the ring to be erected. It was rotated by a chain gear moved by two hydraulic rams. The erector itself was a hydraulic ram with devices for attaching the end of the piston rod to a segment to be erected. A segment could thus be picked up, the erector rotated, and the segment pushed into place by the erector.

With a suitable shield and an experienced working force the operation of tunnelling under the North River became mainly one of erecting tunnel lining, and the men became very proficient. A ring was frequently erected in 30 minutes; the maximum day's work was 15 rings, or 37½ lineal feet of tunnel, done in two 8-hour shifts. One gang working eight hours erected 8 rings, or 20 lineal feet of tunnel. They promptly advertised as the "8-ring gang," and were in evidence on exhibition occasions.

It was not necessary in North River mud to raise the air pressure to meet the full hydraulic head except when working



PENNSYLVANIA RAILROAD

NORTH RIVER TUNNELS

outside the diaphragm, as, for example, when cutting off piles projecting below the top of the shield. In such cases the pressure would be raised, effecting a stiffening of the mud and making it practicable to excavate a small volume, protecting carefully by timbering, and to remove the obstruction.

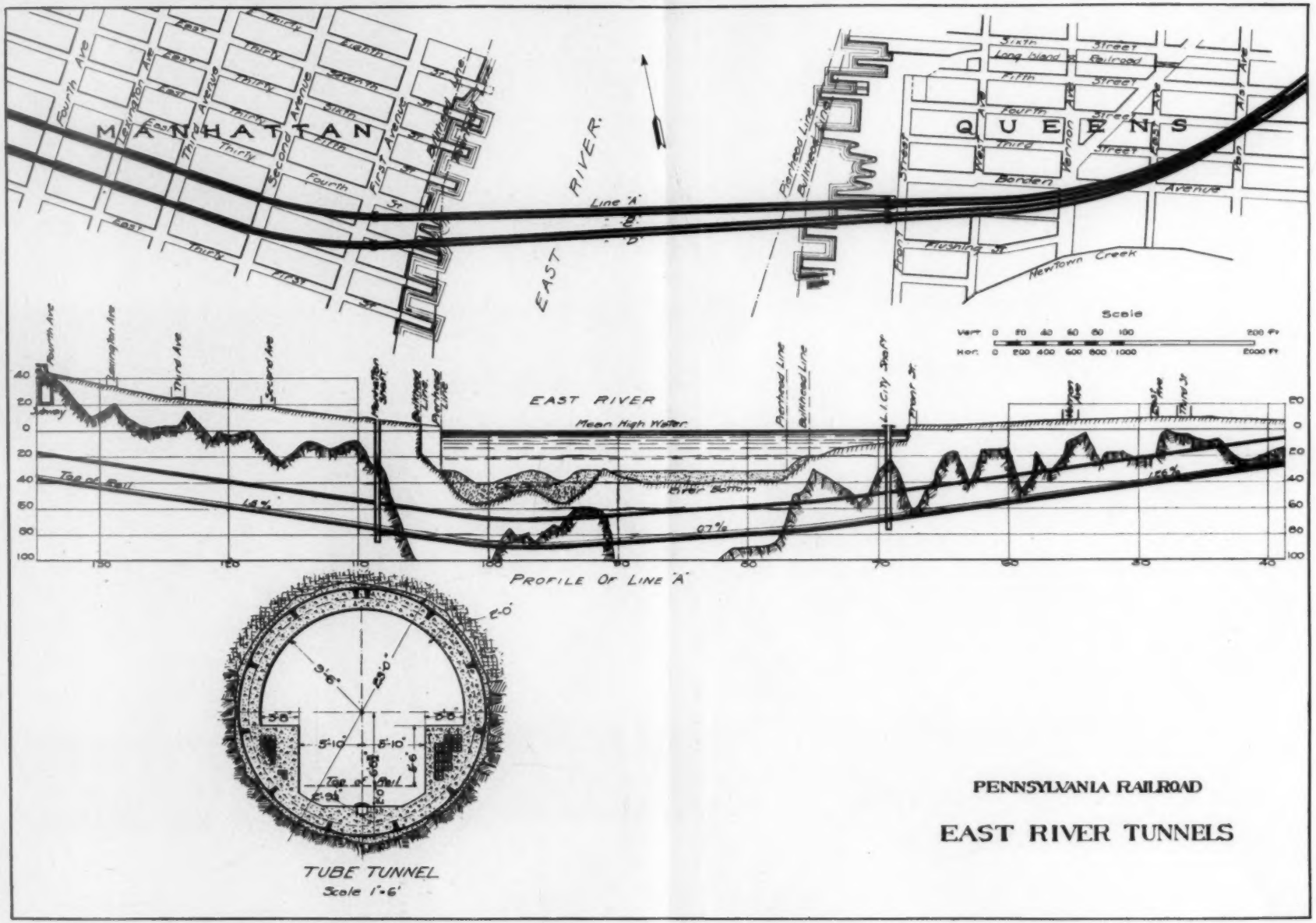
On account of the low air pressure usually carried, "blows," so-called, were infrequent. These are among the most picturesque, costly, and hazardous incidents of shield tunnelling. They can be dealt with more appropriately in connection with the East River tunnels, where they occurred with appalling frequency.

Pushing the shield through the mud without excavating the full tunnel displacement resulted in a ridge along the bed of the river over the tunnel lines as revealed by soundings. For some distance eastward from the river bulkhead on the Manhattan side the tunnels were driven under a freight yard of the New York Central Railroad, with the result of lifting the surface, which was some 50 feet above the tunnel (Plate 21).

During a period of many years preceding the inauguration of traffic through the uptown tunnels of the McAdoo system there was much discussion in regard to the stability of tunnels in the North River mud. They were to sink in the mud; when it was pointed out that the cast-iron tubes weighed less than the displaced mud, or less, even, than the same volume of water, then the mud was said to be a viscous fluid through which the tubes would certainly rise. It was even urged that the bed of the river was a mass of flowing mud gradually but surely moving into the upper bay. These views were little affected by the fact that the Haskin-Moir tunnel had neither risen nor moved down stream, so far as could be ascertained. Still, it seemed possible that the condition of the material might change under the vibration set up by traffic, being more liquefied and causing the tunnels to rise or sink—views differed as to the direction. In order to meet this contingency plans were made to sink screw piles through the bottom of the tube, and their sufficiency either to carry loads or to serve as anchors fully tested by experiment. Before it became necessary to place them in the due progress of the work the uptown McAdoo tunnels had been in operation for several months without any of the dire results apprehended, giving confidence that the supports would not be required, and they were omitted.

PLATE 21

Surface of ground lifted by shield.


MANHATTAN
QUEENS
EAST RIVER
Line 'A'
Pennsylvania Railroad
Bullhead Line
Fourth Ave
Lexington Ave
Third Avenue
Second Avenue
First Avenue
East Thirty
Fourth St
Sixth Street
Long Island Railroad
Fifth Street
Vernon Ave
Borden Avenue
Flushing St
Newtown Creek
Scale
Vert 0 20 40 60 80 100 200 Ft
Hor 0 200 400 600 800 1000 2000 Ft
EAST RIVER
Mean High Water
River Bottom
Top of Rail
1.4%
0.7%
PROFILE OF LINE 'A'
TUBE TUNNEL
Scale 1"-6'
PENNSYLVANIA RAILROAD
EAST RIVER TUNNELS

PENNSYLVANIA RAILROAD TUNNELS UNDER EAST RIVER.

The materials met with under East River were very different from those just referred to. For about half the distance under the river the excavation was in sand, with a little clay, mostly quicksand (Plate 22). Rock, wherever met, was overlaid by a few feet of gravelly material freely water-bearing. Here were practically two new problems: one where the excavation was partly in rock with open gravel over it. At the Blackwall tunnel under the Thames, built a few years before, the excavation was in gravel, but was not complicated by blasting rock, which in East River frequently brought down the timbering by which the face above was protected. A face partly in rock was met previously, as already mentioned, in the north tube of the uptown McAdoo tunnel in 1903, but the overlying material held air better. The other problem—tunnelling in quicksand—was far more difficult. These problems were being met almost simultaneously in the city tunnels between South Ferry and Brooklyn, but were less difficult there because of the smaller diameter of the tunnels and the lighter shields. The increase of diameter from about 17 feet in the McAdoo and city tunnels to 23 feet[5] in the Pennsylvania Railroad tunnels nearly doubled the area to be excavated; the weight of metal in the lining and the amount of compressed air required increased even more.

The shields were designed under the direction of E. W. Moir, a member of the same contracting firm for whom as engineer he designed the shield used in the North River tunnel in 1889. They were massive, weighing about 270 tons each when fully equipped, and cost about $44,000 each. The cutting edge was made up of heavy steel castings, as already described. There were 27 hydraulic jacks, each 9 inches in diameter, to move the shields forward. A push of 5600 tons has been exerted, but under ordinary circumstances 3000 to 4000 tons were sufficient. Each shield carried two erectors. Because of the unprecedented conditions many ingenious devices were provided to facilitate the excavation. When put in use they failed quickly, and simpler and stronger devices were adopted.

The tunnels approaching the river from the central station

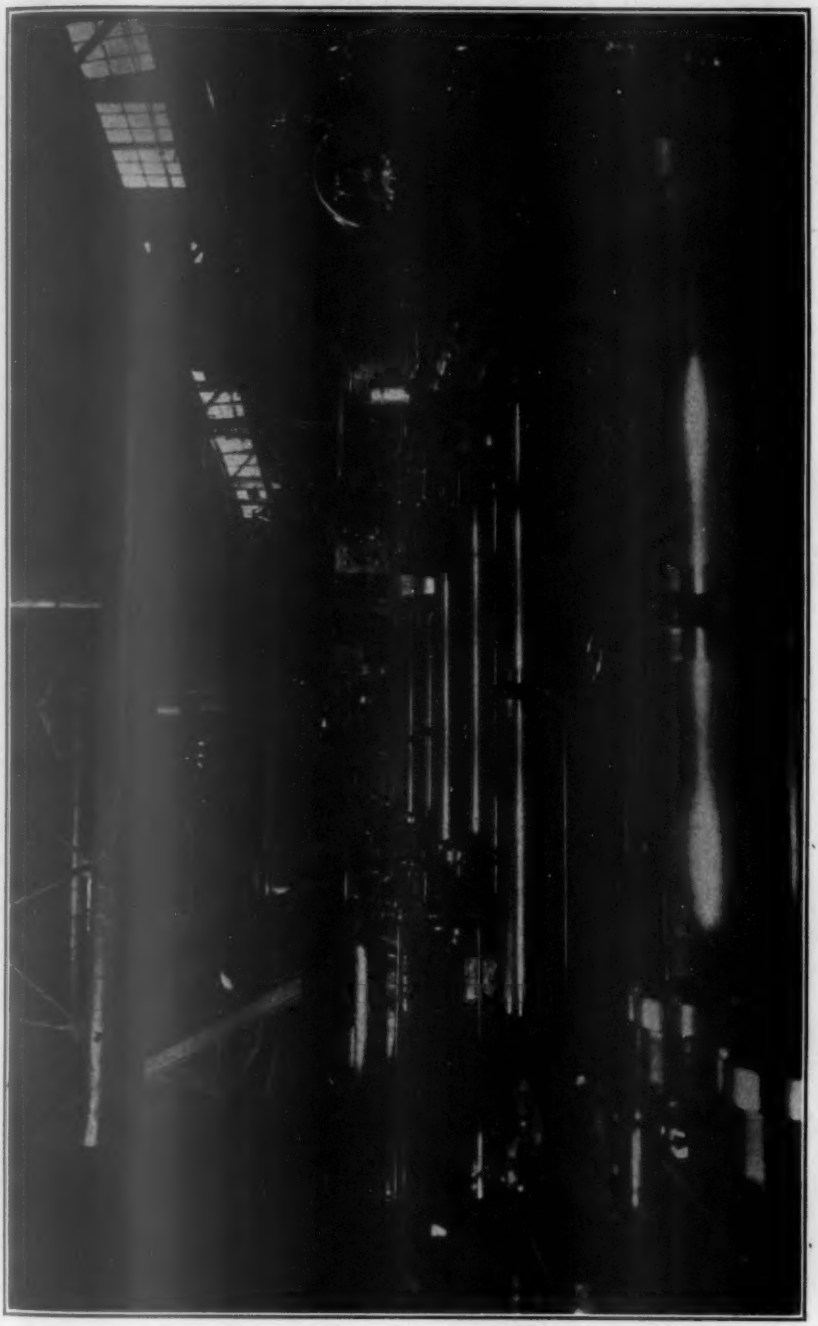
[5] For details of dimensions and weight of cast-iron tunnel lining see table on page 384.

were in pairs, one pair under Thirty-second Street, the other under Thirty-third Street, as already explained. At the working shafts near the river on the Manhattan side the tunnels of each pair were 11 feet apart, and at the Long Island City shafts 14 feet apart. It was convenient, therefore, to make each shaft large enough to cross both tunnels of a pair. Each shaft was a steel caisson; the two on the Manhattan side were about 300 feet from the river, and were sunk without compressed air. The Long Island City shafts were on the river side of the bulkheads, and compressed air was used; after sinking to full depth a strong concrete floor was put in below the tunnel level and the roof of the caisson removed. The shields for the work under the river were then built inside the shafts, the caisson roof with suitable airlocks replaced above the tunnel level, compressed air put on, and the shields started on their way. On the Manhattan side the shields were also built in the shafts and then pushed eastward, in tunnel excavation previously made, the cast-iron tunnel lining being built as the shields were moved forward, and the space between the tubes and the rock thoroughly filled with riprap and cement grout. After moving about 100 feet, nearly to the place where the shields would break out of rock, airlock bulkheads were built between the shields and the shafts and compressed air put on. Quicksand was met almost immediately after breaking out of rock, and the most serious difficulties of the work were at once encountered, with methods unperfected and working force untrained.

One of the difficulties anticipated and encountered was the escape of large quantities of air from the face of the heading, and two precautions were taken: one consisted of covering the bed of the river over the tunnel with a thick bed of clay to hinder the escape of air through it, and this proved very helpful. The amount thus used was more than 300,000 cubic yards, most of it obtained from a place 35 miles distant. After the tunnels were built this clay had to be removed and dumped at sea, a distance of about 24 miles. This was a large item of cost, but there is no doubt that it was wisely incurred. The other precaution taken was to provide a very extensive plant for compressing air to be sent into the tunnels. At the beginning of the work the plant provided on each side of the river to supply four headings had a capacity of 25,000 cubic feet per minute of free air—that

PLATE 23.

PLATE 23.



Pennsylvania Railroad. Manhattan air compressors for East River tunnels.

is to say, measured at normal pressure. The first tunnels to emerge from rock into the quicksand were three on the Manhattan side, and it was quickly found that the plant intended for prosecuting the work simultaneously in four tunnels was barely sufficient for two. The Manhattan plant was enlarged as soon as possible to a capacity of 35,000 cubic feet per minute; the plant on the opposite side of the river was enlarged still more, and finally had a capacity of 45,000 cubic feet of free air per minute. It may be mentioned that the cost of plant of all kinds for the construction of these tunnels was about $2,500,000.

It would be tedious if I were to follow the various methods of working tried and abandoned; the discouragement when it became clear that unless better methods could be devised disaster could hardly be avoided; but we will pass at once to the methods finally developed by which, in the hands of a trained force, success was finally attained.

The successful method in quicksand is illustrated on Plate 24. The right hand portion of the plate represents the stage of the work when the shove of a shield has just been completed; the erection of a ring is being commenced; excavation must be resumed in the face, the breasting planks advanced and strutted, and the condition obtained which is shown in the left-hand side of the view, where the preparation is complete for another shove. It will be readily understood that if the quicksand is fully saturated it will be impossible to advance the planking, because any void excavated will be filled immediately by the liquid quicksand; therefore, the condition of the quicksand must be changed so that it will not flow, or, in other words, it must be dried out. This is effected by maintaining the air pressure slightly greater than that required to balance the hydrostatic head, which results in driving the water back from the face, drying it sufficiently to permit removing the top plank, or the top but one, excavating, and replacing it in the advanced position desired; this gives access behind the next plank, where excavation is made and the plank placed in the new, advanced position, and so on until the entire face has been advanced, with only a small portion open at any time.

It will be noticed that but little more than half the face is shown in the figure as protected, and the question will arise whether the air pressure could be raised sufficiently to dry and

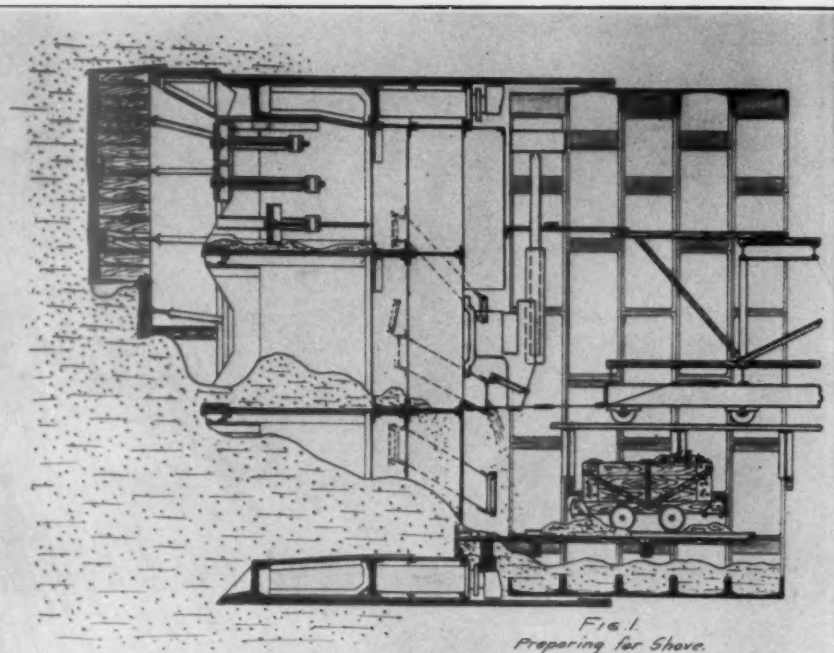


FIG. 1.
Preparing for Shove.

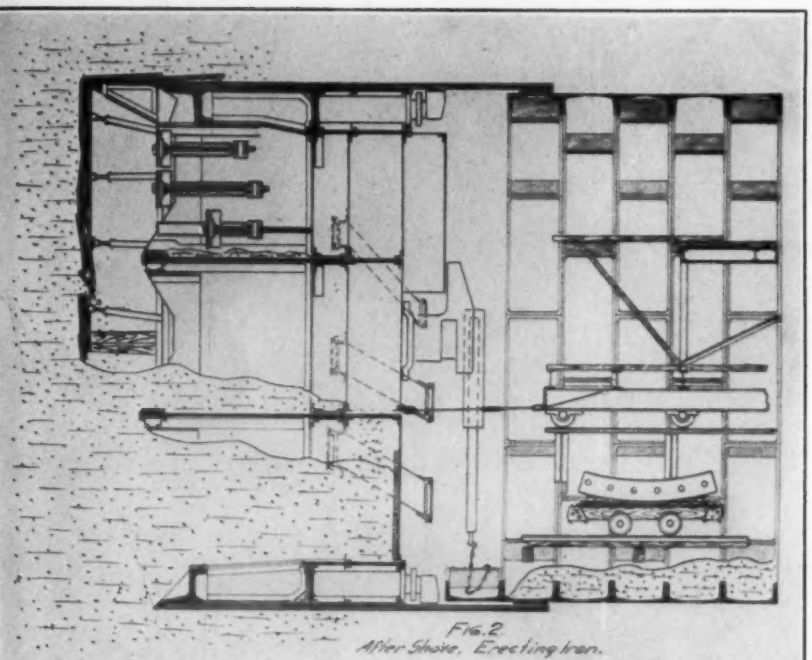


FIG. 2.
After Shove. Erecting Iron.

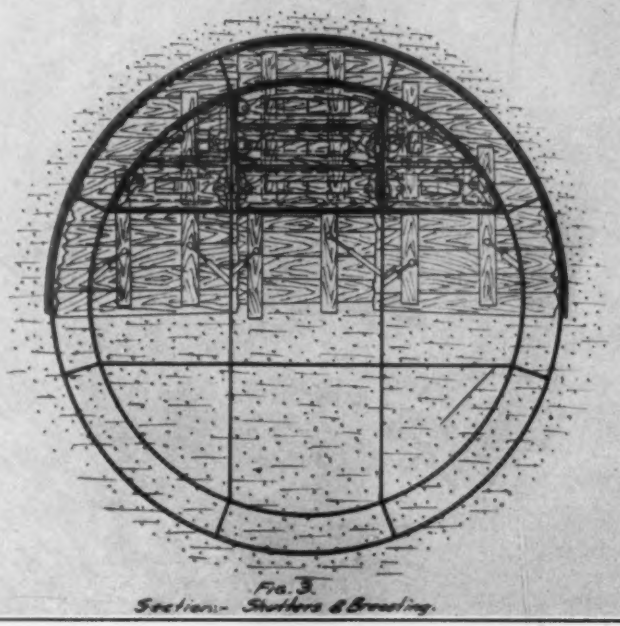


FIG. 3.
Section - Shutters & Breasting.

Pennsylvania Railroad, East River tunnels. Method of tunnelling in quicksand.

plank the heading to the very bottom. In quicksand this was not necessary, for it was found practicable to shove the shield forward when in the condition shown in the left-hand figure—the operation being to apply the pressure to the jacks and shovel the sand back from the bottom pockets as vigorously as possible; the facility thus given for more material to enter the bottom pockets tends to relieve the resistance at the cutting edge. It was found extremely dangerous to raise the pressure sufficiently to dry the sand at the bottom of the excavation, as will be briefly explained. Of course, the air pressure in the tunnel is practically the same everywhere at any given moment, but in a tunnel 23 feet in diameter the water pressure in the face is about 10 pounds per square inch greater at the bottom than at the top; therefore, if the air pressure were raised sufficiently to dry the materials at the bottom, the excess pressure at the top would be ten pounds per square inch. Under such a pressure the escape of air through the joints of the facing plank would become very great; the sand would soon be carried away in considerable quantity; an opening would be forced through the overlying earth; the escape of air would be then greatly increased, and some portion of the planking, deprived of the earth backing, would collapse, and the air would rush out in large volume, forming what is known as a "blow."

Usually, in the East River tunnels, the air balanced the water near the tunnel axis, varying with the nature of the material and the skill and judgment of the tunnel boss. With firmer material than quicksand, the planking was carried farther down, as shown in Plate 25, the material in the central portion containing more clay, holding air better, and flowing less readily, with gravel in the bottom giving greater resistance to the forward movement of the shield.

Even when skill had been acquired and care was exercised the escape of air would sometimes get beyond control. I have no doubt that as much as 40,000 to 50,000 cubic feet per minute was blown out during short periods from a single heading. The escape has been as much as 25,000 cubic feet per minute for 24 hours or more. The most effective way to stop a blow was to dump quickly a large amount of clay from a dump scow.

Many blows were checked in their incipient stage in the tunnel by throwing bundles of hay or sacks or balls of clay into

PLATE 25.

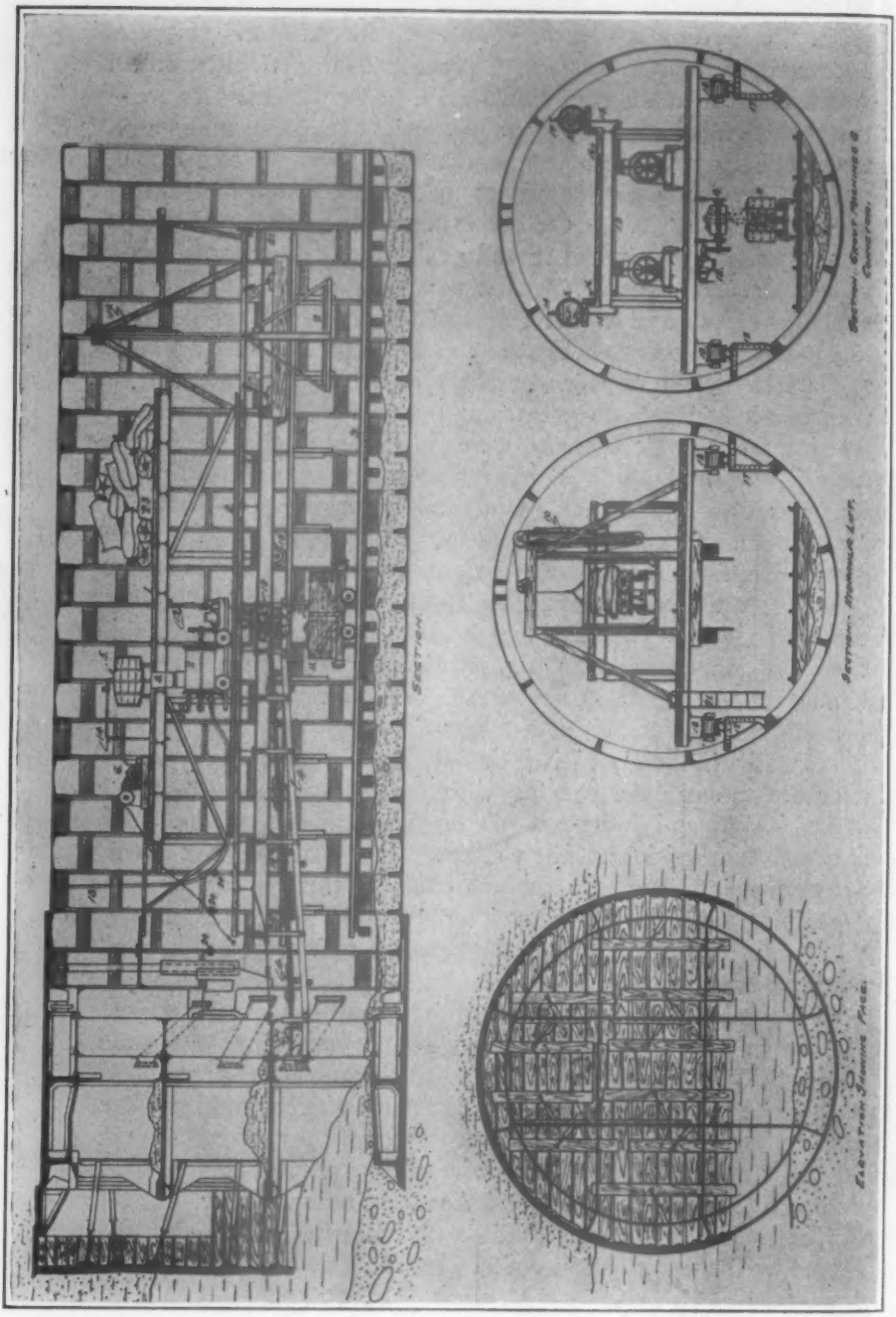
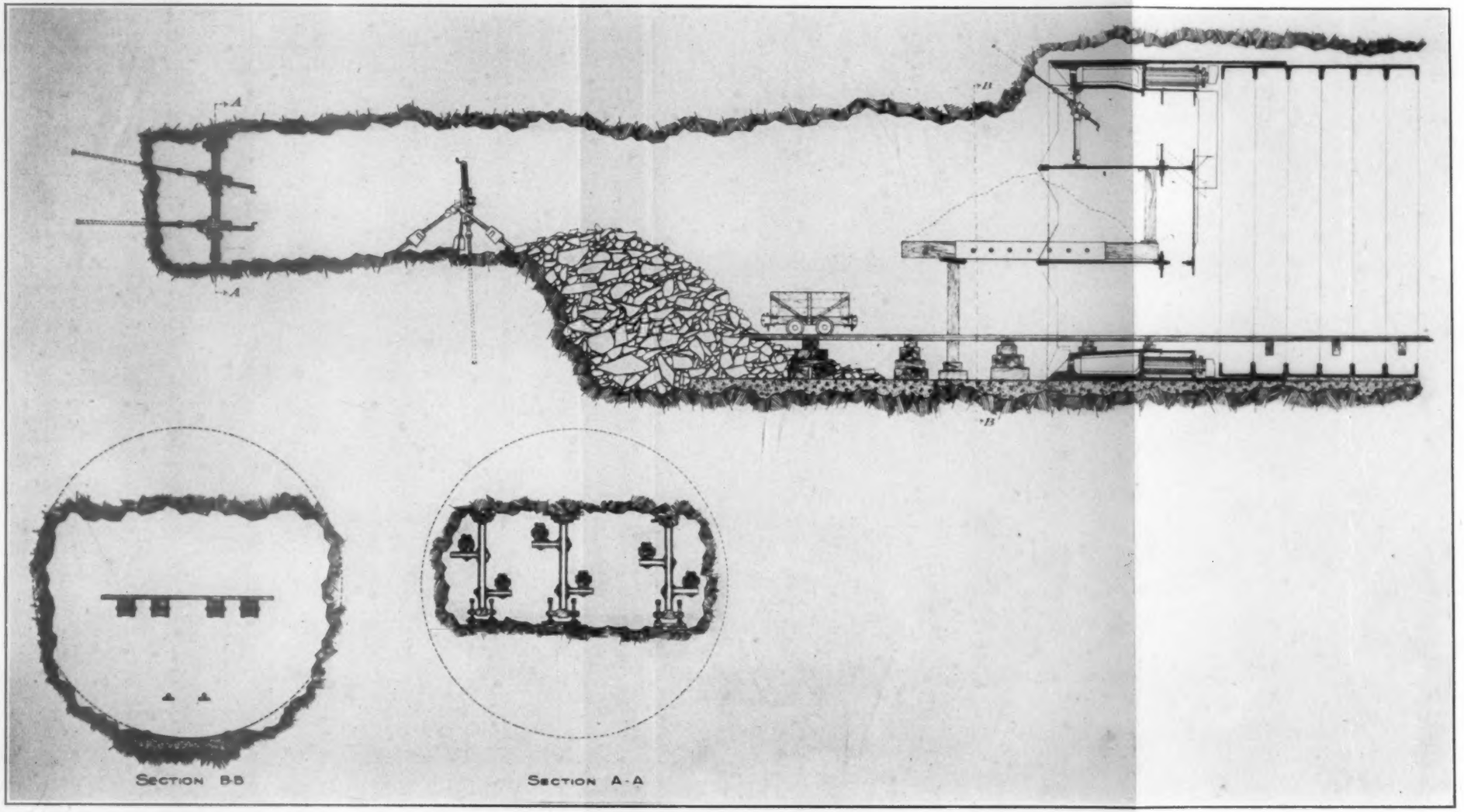
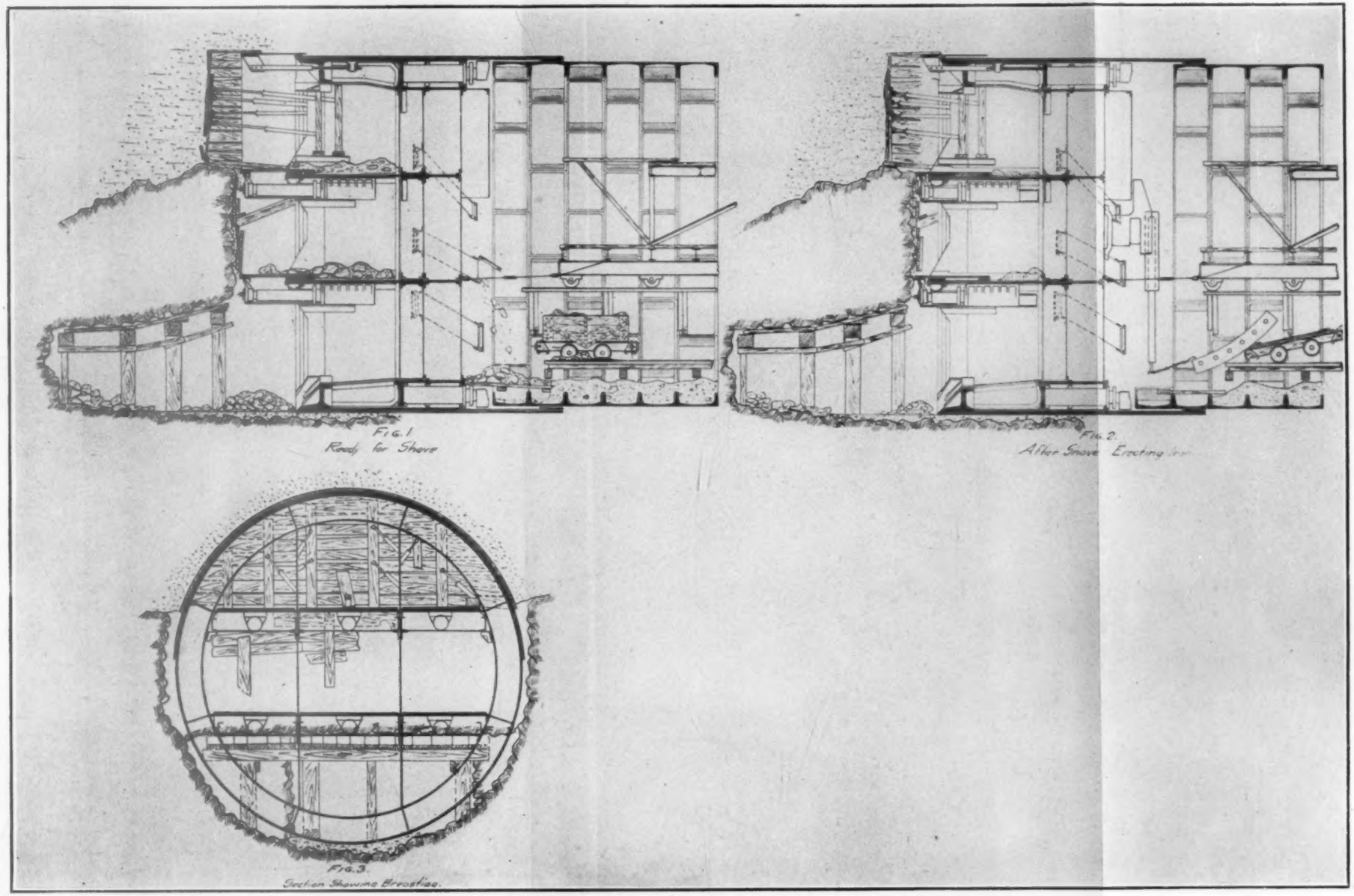

SECTION.
SECTION, GREAT RUNNER & CONNECTION.
SECTION, ADMIRALTY LEVEL.
ELEVATION SHOWING PIPES.

PLATE 26.



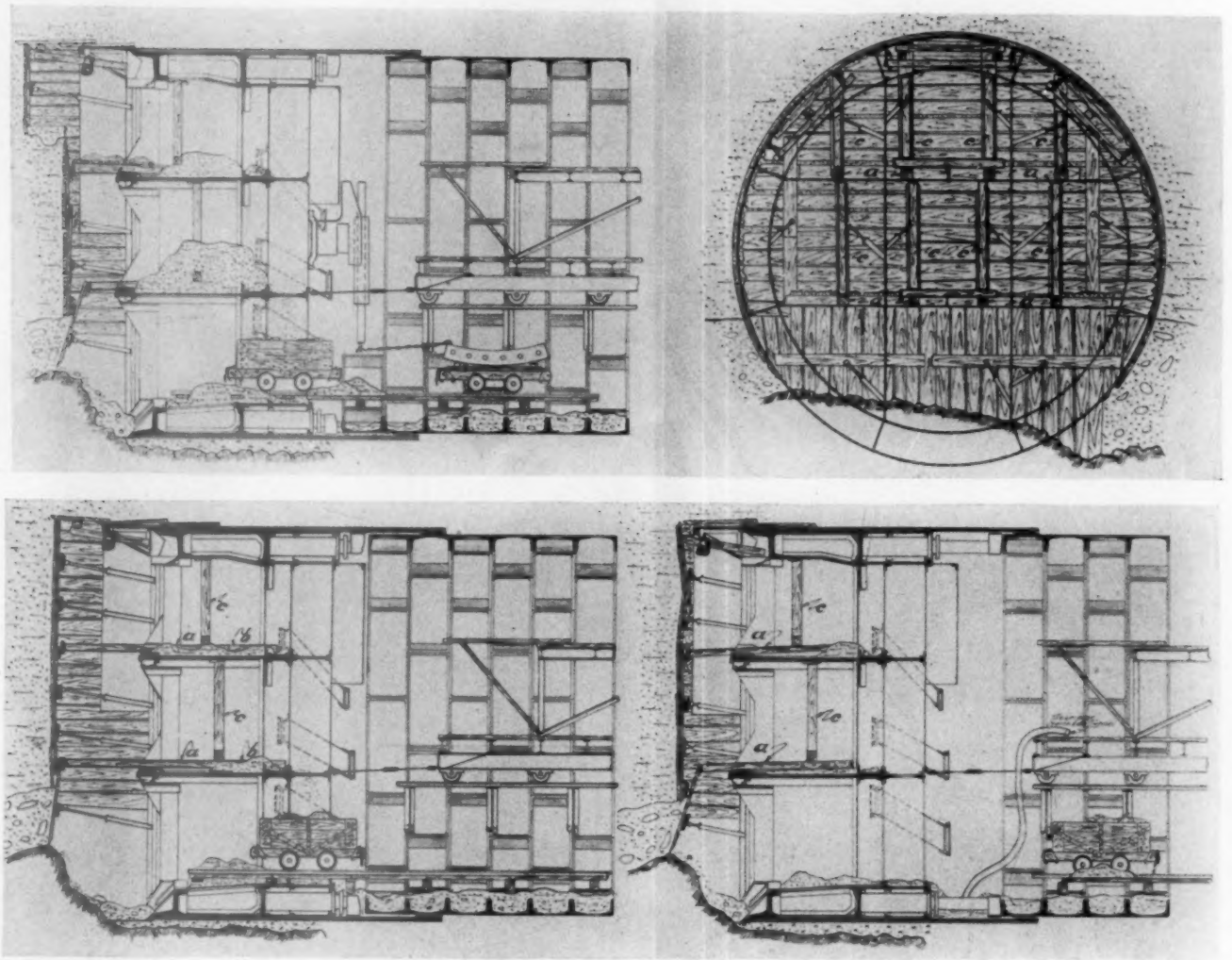
Pennsylvania Railroad, East River tunnels. Method of tunnelling in rock.

PLATE 25.



Pennsylvania Railroad East River tunnels. Method of tunnelling free rock and earth. Bottom heading.

PLATE 28.



Pennsylvania Railroad, East River tunnels. Method of tunnelling, rock in bottom.

PLATE 25.

the opening being formed. This involved much danger to the men attempting it; if the attempt failed and a great outrush of air occurred the men were liable to be drawn into it and disappear in the river bed. Several such cases have occurred in recent years; only one man has escaped after being drawn into the opening.

A very severe blow, one wrecking the face protection, would be followed by an inrush of water and earth, and not only the men in front of the shield but those in the tunnel would be in danger.

It will doubtless be realized from this description that success depended on experience acquired on that work. In the early period progress averaged less than a foot a day for many weeks. In the first tunnel the shield settled a foot below the desired grade in moving a distance of 25 feet; many tunnel castings were broken; the risks constantly met were appalling; a large loss to the contractors seemed impending, and the railroad company's entire terminal project seemed at stake. The sensible course was taken by suspending work in this tunnel, giving the quicksand time to settle together and become compacted, and transferring the working force to other tunnels where the difficulties were somewhat less. Methods were studied and improved from day to day, and when work was resumed in the troublesome tunnel no great trials were encountered. The daily programme increased steadily, and finally became an average of 10 feet per day, month after month, and the contractors made a handsome profit.

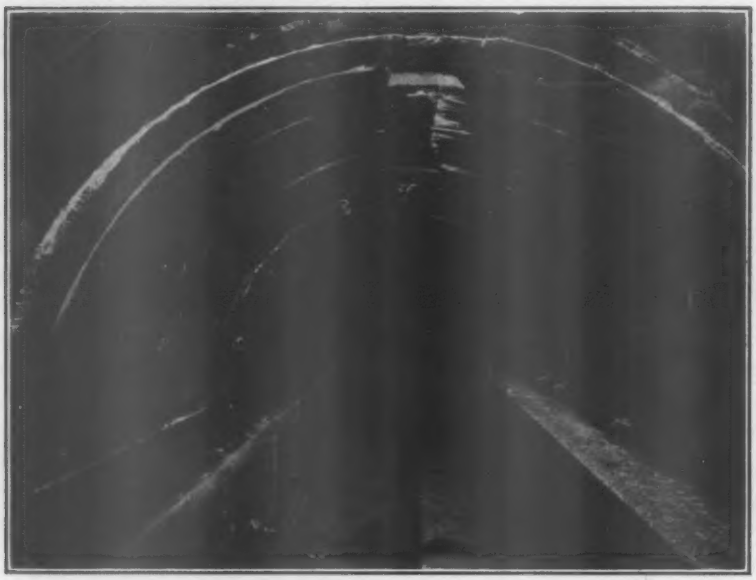
When rock was encountered, percussion air drills were used. Where the excavation was all rock the method finally adopted was to drive a large centre heading 30 feet or more in advance (Plate 26). The bench was also taken out well in advance of the shield. A light track was laid through the shield for the muck cars, and the greater part of excavation was thus kept at some distance from the shields. The drilling for enlargement to full size was done with drills mounted in the forward part of the shield. With these arrangements the average daily programme became about 3 feet.

Where the surface of the rock was a little below the top of the tunnel the heading was smaller and usually became a bottom heading, and in poor rock could not be kept far in advance of

the shield (Plate 27). Where the rock was not high enough to permit driving a heading the rock was all excavated immediately in front of the shield (Plate 28), and the progress was the slowest under this condition. Whenever the rock surface was below the top of the tunnel some form of timbering the earth face above the rock was necessary.

As the shields approached each other from opposite sides of the river some anxiety in regard to the accurate meeting of the two headings was unavoidable.

PLATE 29.



Pennsylvania Railroad, East River tunnels. View in completed tunnel.

As a precautionary measure, the relative positions of the approaching shields were ascertained while they were some 50 or 60 feet apart by pushing a large pipe from the face of one heading to the other, through which line and levels were checked, and accurate meetings of the shields assured. In the four East River tunnels the discrepancies in alignment and levels varied from ⅛ inch to ⅜ inch, with an average of ¼ inch.

The placing of the concrete lining followed next. The view (Plate 29) shows a tunnel lined with concrete and ready for

track. The trough-like form of section was devised by Mr. A. J. Cassatt, late president of the Pennsylvania Railroad. The width of the trough is about one foot greater than that of the widest Pullman car now in use, and the benches are a few inches below the level of the car windows. It is believed that in case of derailment the train will come to a stop without a shock and passengers may reach the benches readily from the platforms or the windows.

LEAKAGE IN PENNSYLVANIA RAILROAD RIVER TUNNELS.

The cast-iron lining is an effective waterproofing, and, while not absolutely water-tight, the leakage is insignificant. A sump of some form is provided at the lowest point of each tunnel or pair of tunnels and pumped out when necessary by pumps regularly installed. The daily leakage into the 5½ miles of river tunnels of the Pennsylvania Railroad is 2300 gallons. The magnitude of this may be better appreciated by stating that it amounts to one drop per lineal foot of tunnel every 17 seconds, or by stating that the entire amount of leakage for one day would be removed in one or two minutes by a pump of the capacity ordinarily used by contractors for foundations. The pumps provided at the new dry docks at the Brooklyn Navy Yard would remove the day's leakage in about two seconds.

OPERATION.

The tunnels eastward from the station were put in operation for the use of the Long Island Railroad, September 8, 1910; the entire system came into use November 27, 1910, and has continued in service without interruption of any kind.

VENTILATION OF RIVER TUNNELS.

While doubt was entertained as to its necessity, mechanical ventilation was provided for all the tunnels except the Hudson River tunnel, largely as a measure of insurance; if not provided and found required after the tunnels were put in use the resulting loss in traffic might not be recovered for a long time. Experience has shown that the movement of trains, forcing the air ahead, causes an entire change of air in the Pennsylvania Railroad tunnels within a short time, and the fans provided for

ventilation are not used. They may prove useful, however, in the possible occurrence of fire in the tunnel, to remove smoke and facilitate the escape of passengers. Such an occurrence, by reason of the extraordinary precautions taken, is an extremely remote contingency. In the Hudson and Manhattan Railroad tunnels, where the distances between shafts are greater, the fans are used occasionally.

TABLE OF DIMENSIONS AND WEIGHTS OF CAST-IRON TUNNEL LININGS.

Tunnel.	Outside diameter of tube.	Width of ring.	Minimum thickness of metal.	Width of flanges.	Weight per lin. ft. of tunnel, lbs.	
Hudson & Manhattan:						
Uptown:						
Moir's section (1889).....	19′ 6″	20″	1¼″	9″	8,280	
New sec.(1902):						
North tube....	19′ 5¼″	20¼″	1½″	8″	7,565	
South tube....	16′ 7″	24″	1⅜″	8″	5,670	Standard.
South tube....	16′ 7″	18″	1⅜″	8″	6,340	Heavy.
Downtown.....	16′ 7″	24″	1⅜″	8″	5,670	Standard.
South tube.....	16′ 7″	18″	1⅜″	8″	6,340	Heavy.
N. Y. City Subway.	16′ 8″	22″	1⅛″	7″	3,992	In rock and above water in earth.
Manhattan to Brooklyn.....	16′ 8½″	22″	1⅛″	7½″	4,545	Standard.
	16′ 8½″	22″	1⅛″	7½″	5,133	In Brooklyn slip.
	16′ 8½″	22″	2″	7½″	5,593	Under bulkhead.
Belmont.....	16′ 10″	26″	1⅛″	8″	4,615	
Pennsylvania R. R.:						
North River Div...	23′ 0″	30″	1½″	11″	9,609	Standard.
North River Div...	23′ 0″	30″	2″	11″	12,127	Heavy.
East River Division.	23′ 0″	30″	1″	8″	5,166	Under land; full rock section.
East River Division.	23′ 0″	30″	1¼″	9″	6,776	Under land; surface of rock between top and centre of tunnel.
East River Division.	23′ 0″	30″	1½″	11″	9,102	Standard.

Spectrographic Study of Tellurium. WM. L. DUDLEY and E. V. JONES. (*J. Am. Chem. Soc.*, xxxiv, 995.)—Tellurium, well purified, was converted into the tetra-chloride, and fractionally precipitated by hydrazine hydrochloride. The spectrographs of 20 fractions showed no variations, except that in the last fractions copper lines appeared. On this basis the theory of a higher homologue as an impurity is rejected, and the authors are led to account for the anomaly of the atomic weight of tellurium by the assumption that it is "a mixture of nearly equal parts of substances differing but little in atomic weight and remarkably similar in other properties."

RECENT DEVELOPMENTS IN STEAM TURBINES.*

BY

H. T. HERR,

Vice-President and General Manager, The Westinghouse Machine Company.

APPENDIX I.

THERMODYNAMICS.

I. The first law of thermodynamics is the law of the conservation of energy,—heat being a form of energy.

First Principle.—When a body does work, it loses an amount of energy equal to the work done, because its energy is its capacity for performing work.

Second Principle.—When work is done on a body it gains an amount of energy equal to the work done, because the body which does the work loses that amount.

Third Principle.—When heat is supplied to or abstracted from a body, it gains or loses that amount of energy, because heat is a form of energy.

To place these principles in the form of an expression and to deduce the first thermodynamic equation:

Let W'' = work done by a body.
Let W' = work done on a body.
Let Q'' = heat supplied to a body.
Let Q' = heat abstracted from a body.

Then the gain of energy of the body = $Q'' + W'$,
and the loss of energy of the body = $Q' + W''$.
Subtracting the loss of energy from the gain of energy gives:

Effective gain of energy = $Q'' + W' - Q' - W''$.
Let E'' = the final energy of a body.
Let E' = the initial energy of a body.

Then the effective energy = $E'' - E'$.
From the above:

$$E'' - E' = -(W'' - W') + (Q'' - Q') \quad \ldots\ldots\ldots\ldots (1)$$

*Continued from page 327

If W represents the effective work, and Q represents the effective heat supplied, we have from (1)

$$E'' - E' = -W + Q,$$

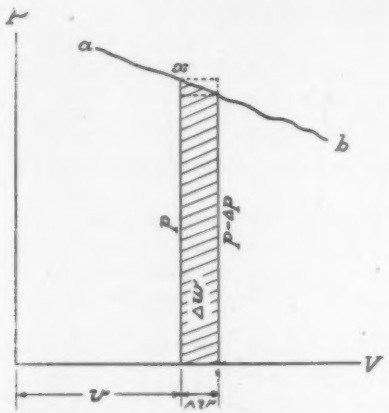
which is the first equation of thermodynamics.

II. The second law of thermodynamics states that it is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature.

In consequence of the second law, no heat engine converts, or can convert, more than a small fraction of the heat supplied to it into work, a large part being necessarily rejected as heat.

The ratio $\frac{\text{heat converted into work}}{\text{heat taken in by the engine}}$ is always a fraction much less than unity. This fraction is called the thermodynamic efficiency.

FIG. A.



In every heat engine there is a working substance, which alternately takes in and rejects heat. In general, it suffers changes of volume and does work by overcoming resistance to these changes. The working substance may be gaseous, liquid, or solid. In almost all actual heat engines, however, the working substance is a fluid. In some it is air, in some a mixture of several gases. In the steam engine the working fluid is steam or a mixture (in varying proportions) of water and steam.

With a fluid for working substance, work is done by changes of volume only, and its amount depends solely on the relation of pressure to volume during the change, and not at all on the form of the vessels in which it takes place.

III. The general expression for the work done by a fluid in expanding may be deduced as follows:

As has been stated, the work done is some function of the volume, or $W = f(v)$.

Let Fig. A represent a pressure volume diagram on which pressures are plotted as ordinates and volumes as abscissæ.

Suppose a fluid expands from initial pressure and volume at point a, tracing any line such as ab. At any point such as x, let the pressure be represented by p and the volume by v.

At any point on the curve ab, closely adjacent to x, the pressure would be $p - \triangle p$ and the volume $v + \triangle v$.

Let $\triangle W$ represent the area under the curve ab between the ordinates p and $p - \triangle p$.

From the figure:

Area $\triangle W$ is less than area $p\,(\triangle v)$.

Area $\triangle W$ is greater than area $(p - \triangle p)\,(\triangle v)$.

Divide these inequalities by $\triangle v$:

$$\frac{\triangle W}{\triangle v} < p$$

$$\frac{\triangle W}{\triangle v} > p - \triangle p$$

If $\triangle v$ approaches zero as a limit, the derivative of W with respect to v is not greater than p, or

$$\frac{dW}{dv} \not> p, \text{ also,}$$

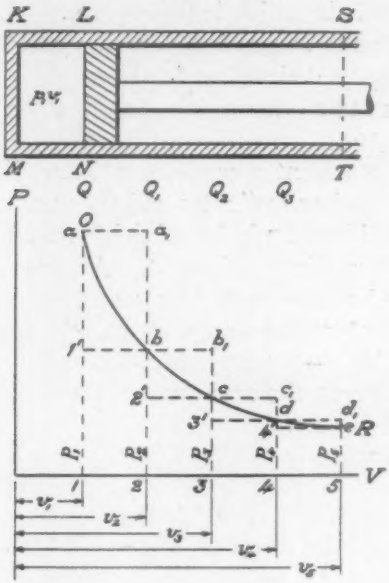
$$\frac{dW}{dv} \not< p.$$

Therefore since $\frac{dW}{dv}$ is neither greater nor less than p, $\frac{dW}{dv} = p$, which is the general expression for the work done by a fluid in expanding.

IV. To prove that the work done by a fluid in expanding is

represented by the area under the curve as plotted on the pressure volume diagram:

FIG. B.



Let Fig. B represent a cylinder and piston, and let the dotted line *ST* be the position of the piston *NP* at the end of the stroke. Let *KLMN* be a body of gas at p pressure and v volume.

On the pressure volume diagram, let the point *O* represent the pressure and volume of the gas in the cylinder at any instant; then, as the gas expands by the movement of the piston to the end of the stroke, it will trace the line *OR*.

Then the line *OR* will represent the action of the gas during expansion.

Let A = area of piston LN.
Let $S = MN$.
Let ΔS = small movement of piston, such as from Q to Q_1, Q_1 to Q_2, etc.
Let p_a = the average pressure from the first to the second position of the piston; then

$$p_2 < p_a < p_1.$$

Multiplying this inequality by $(v_2 - v_1)$

$$p_2 (v_2 - v_1) < p_a (v_2 - v_1) < (p_1 (v_2 - v_1).$$

Since the average force on the piston is the area times the pressure:

Average force = $(p_a A)$, and the work done $(\triangle W_1)$ in the first movement of the piston is:

$$\triangle W_1 = p_a A \triangle S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Also,
$$v_1 = AS$$

Subtracting
$$v_2 = A\,(S + \triangle S)$$
$$v_2 - v_1 = A \triangle S$$

Substituting in (1) $\triangle W_1 = p_a\,(v_2 - v_1)$

From Fig. B:

$$\text{Area } 11'\,b2 < \triangle W_1 < 1aa'\,2$$
$$\text{Area } 22'\,c3 < \triangle W_2 < 2bb'\,3$$
$$\text{Area } 33'\,d4 < \triangle W_3 < 3cc'\,4$$
$$\text{Area } 44'\,e5 < \triangle W_4 < 4dd'\,5$$

Adding these inequalities:

$$\text{Area } 11'\,b2'\,c3'\,d4'\,e5 < W < 1\,aa'\,bb'\,cc'\,dd'\,5$$

By taking the division indefinitely small, it is apparent that W = area under the curve.

V. *Cyclic Process.*—When a body goes through a series of states and returns to its original state, it is said to perform a cyclic process.

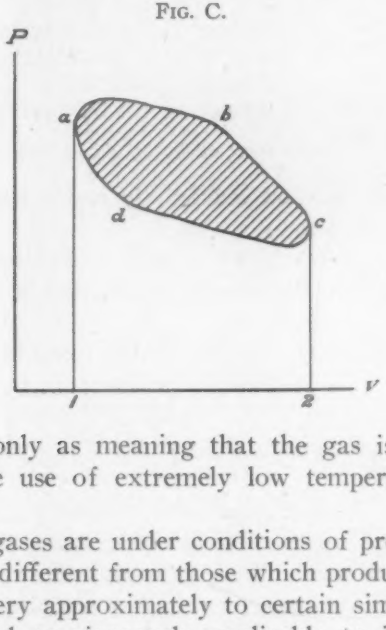
The first equation of thermodynamics is given in 1: $E'' - E' = -W + Q$. For a cyclic process, since the body returns to its inital state, $E'' = E'$. Therefore $-W + Q = 0$. Hence $Q = W$, or in a cyclic process the work a body does is equal to the heat supplied.

Generally, in heat engines, the working substance returns periodically to the same state of temperature, pressure, volume, and physical condition. Each time this has occurred the substance is said to have passed through a complete cycle of operations. For example, in a condensing steam engine, water taken from the hotwell is pumped into the boiler; it then passes into the turbine or cylinder as steam, passes thence into the condenser, and again as water into the hotwell, and completes the cycle by returning to the same condition as at first obtained.

In the theory of heat engines it is of first importance to consider as a whole the cycle of operations performed by the working substance. If each cycle is not completed, matters are com-

plicated by the fact that the substance is in a state different from its initial state, and may therefore have changed its stock of internal energy. After the cycle is completed, however, the internal energy of the substance is necessarily the same as at first, since the condition is in every respect the same. Hence, in a cyclic process, the following equation must hold good: Heat taken in = work done + heat rejected. In approaching the theory of heat engines, it is convenient, in the first instance, to consider the action of an engine in which the working substance is any one of the so-called permanent gases, or a mixture of them, such as air. The word "permanent," as applied to a gas, is to

FIG. C.



be understood only as meaning that the gas is liquefied with difficulty by the use of extremely low temperature and high pressure.

So long as gases are under conditions of pressure and temperature widely different from those which produce liquefaction, they conform very approximately to certain simple laws which may be regarded as rigorously applicable to ideal substances called perfect gases.

These laws are very nearly, though not absolutely, true for air, oxygen, nitrogen, hydrogen, and carbonic oxide, except when these are at specially high pressures or low temperatures. Hydrogen probably comes nearest to the ideal of a perfect gas.

A cyclic process is represented on a pressure volume diagram by a closed curve, such as in Fig. C, and the work done is repre-

sented by the area enclosed by such curve. This may be readily understood by taking the point *a* as the initial and final state of a fluid after passing through the cyclic process represented in Fig. C, and from consideration of the first and second laws of thermodynamics.

Thus:

W'' = area *abc*21 = work done by the body.
W' = area *adc*21 = work done on the body.
Therefore W = area *abcd*.

VI. Perfect gases have been found to comply with the four following laws, commonly called after their discoverers:

Law 1 (Boyle).—The volume of a given mass of gas varies inversely as the pressure, provided the temperature be kept constant. Thus if v be the volume of a given quantity of any gas and p the pressure, then so long as the temperature is unchanged v varies inversely as p, or pv = constant.

Law 2 (Charles).—Under constant pressure equal volumes of different gases increase equally for the same increment of temperature; also, if the gas be heated under constant pressure, equal increments of its volume correspond very nearly to equal intervals of temperature as determined by the scale of a mercury thermometer.

Experiments show that the amount by which a gas expands when its temperature is changed by one degree Fahrenheit (its pressure being kept constant) is about 1/493 of its volume at 32° F. Thus if 493 cubic inches of air, or any other permanent gas at a temperature of 32° F., is heated to 33° F., its pressure remaining constant, its volume alters to 494 cubic inches; similarly, if the gas be cooled from 32° F. to 31° F., its volume changes from the original 493 cubic inches to 492, and so on. Finally, therefore, its volume would become 0 at —461° F. if the same law could be held to apply at indefinitely low pressures. Any actual gas would change its physical state before so low a temperature were reached.

The above may be concisely expressed by saying that if temperature be reckoned not from the ordinary zero, but from a point 461° below the zero of Fahrenheit's scale, the volume of a given quantity of gas, kept at constant pressure, is propor-

tional to the temperature reckoned from that zero. Temperatures so reckoned are called absolute temperatures, and the point $-461°$ F. is called absolute zero temperature. Denoting any temperature according to the ordinary scale by t and the corresponding absolute temperature by T, we have $T = t + 461$ on the Fahrenheit scale and $T = t + 274$ on the Centigrade scale.

Law 3 (Regnault).—The specific heat at constant pressure is constant for any gas. By specific heat at constant pressure is meant the heat taken in by one pound of substance when its temperature rises one degree Fahrenheit, while the pressure remains unchanged, the volume being allowed to change. The law states that this quantity is the same for any one gas, no matter what its temperature, or what the constant pressure, at which the process of heating takes place. Another important quantity in the theory of heat engines is the specific heat at constant volume,—that is, heat taken in by one pound of a substance when its temperature rises one degree Fahrenheit, while the volume remains unchanged—the pressure being free to change.

An obvious difference between the heating of a gas at constant pressure and at constant volume is that when heated at constant volume the gas does no work, whereas heating at constant pressure involves the expansion of the gas, and consequently the performance of an amount of work equal to the product of the pressure and the increase of volume.

Law 4 (Joule).—When a gas expands without doing external work and without taking in or giving out heat, and therefore without changing its stock of internal energy, its temperature does not change. This fact was established by the experiments of Joule. He connected a vessel containing compressed gas, by means of a pipe with a closed stopcock, with another vessel which was empty. Both vessels were immersed in a tank of water and were allowed to assume a uniform temperature. Then the stopcock was opened and the gas distributed itself between the two vessels, expanding without doing external work. After this the temperature of the water in the tank was found to have undergone no change. The temperature of the gas was unaltered and no heat had been taken in or given out by it and

no work had been done by it. Since the gas had neither gained nor lost heat and had done no work, its internal energy was the same at the end as at the beginning of the experiment. The pressure and volume had changed, but the temperature had not. The conclusion follows that the internal energy of a given quantity of gas depends on its temperature and not upon its pressure or volume. In other words, a change of pressure and volume not associated with a change of temperature does not alter the internal energy.

From the first law of thermodynamics, $E'' - E' = -W'' + W' + Q$. From Joule's experiment, therefore, $W'' = 0$, as there was nothing to do work on $W' = 0$, as the gas was not compressed; $Q = 0$, as the temperature of the water in the tank was not changed. Therefore $E'' - E' = 0$, or $E'' = E'$; also, $T'' = T'$; hence, if the energy of a body remains constant, the temperature remains constant, and *vice versa*.

VII. The numerical equation, expressed in Boyle's and Charles's laws, may be written $\left(\frac{pv}{m}\right)$ = a constant, when the temperature is constant, and $\left(\frac{v}{mT}\right)$ = a constant when the pressure is constant. In Boyle's law it is apparent that $\left(\frac{pv}{m}\right)$ is some function of T and in Charles's law $\left(\frac{v}{mT}\right)$ is some function of p, or, expressed numerically:

$$\frac{pv}{m} = f(T) \quad \text{.....(1) (Boyle's Law).}$$

$$\frac{v}{mT} = f'(p) \quad \text{.....(2) (Charles's Law).}$$

From (1), $\frac{v}{m} = \frac{f(T)}{p}$ .....(3)

From (2), $\frac{v}{m} = Tf'(p)$ .....(4)

Equating (3) and (4):

$$\frac{f(T)}{p} = Tf'(p), \text{ or}$$

$$\frac{f(T)}{T} = pf'(p) \quad \text{.....(5)}$$

Now $\frac{f(T)}{T}$ is either a constant or a variable. We know we can vary T without varying p; therefore, the right-hand member of 5 is constant; the left-hand member of 5 is assumed variable, but that is impossible; therefore $\frac{f(T)}{T}$ is a constant. Therefore, $fT = CT$.

Substituting this value in equation (1) $pv = mCT$. By experiments for air $C = 53.2$, provided p is in pounds per square foot and v in cubic feet, m in pounds and T in degrees absolute.

VIII. Deduction of the equation for the change of internal energy of a perfect gas: On the pressure volume diagram, Fig. D, let line ab represent the process through which a perfect gas of mass m changes its state from energy E', temperature T', pressure p', volume v' to energy E'', temperature T'', pressure p'', volume v''; also let the line ac represent the process of expansion of the gas at constant pressure, from energy E', temperature T', to energy E''', temperature T'', volume v'''.

From the first equation of thermodynamics:

$$E''' - E' = -W_p + Q_p \text{ (at constant pressure)} \ldots . (1)$$

The work done, as has been shown, is represented by the area under the curve on the pv diagram; therefore,

$$W_p = p'(v' - v') = p'v''' - p'v';$$

also, by the combined law of Boyle and Charles:

$$p'v''' = mCT''$$
$$p'v' = mCT'$$

By substituting in the equation for W_p

$$W_p = mCT'' - mCT' = mC(T'' - T')$$

Let K_p = the specific heat at constant pressure; then by (VI) Regnault's law $Q_p = mK_p(T'' - T')$.

Substituting the values W_p and Q_p in equation (1):

$$E''' - E' = -mC(T'' - T') + mK_p(T'' - T') = m(K_p - C)(T'' - T').$$

Let $(K_p - C)$ = a constant = K.

But by Joule's law, $E''' = E''$, since the points b and c in Fig. D have the same temperature T''.

$$E'' - E' = mK(T'' - T'), \text{ or}$$
$$K_v = K_p - C.$$

IX. Proof that the specific heat at constant volume is constant: On the pressure volume diagram (Fig. E), let one pound of gas expand at constant volume from point a to point b. Let the inital energy and temperature be represented by E', T' and the final energy and temperature by E'', T'', and let $T'' = T' + 1$.

FIG. D.

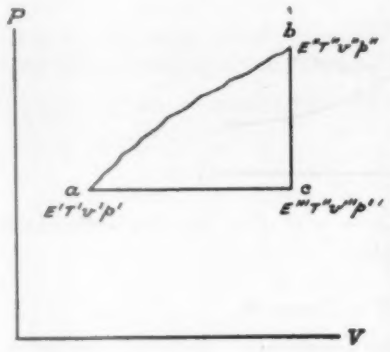
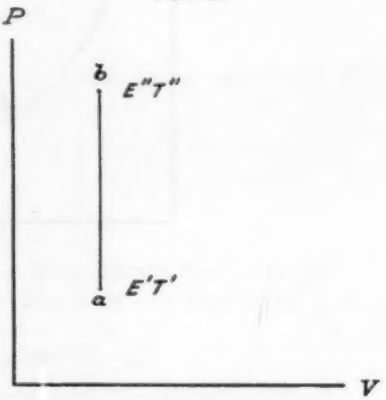


FIG. E.



Let K_v = the specific heat at constant volume; then since one pound of gas has been taken and raised one degree Fahr., $Q_v = K_v (T'' - T')$. $W_v = 0$, since there is no area under the curve.

Substituting in the first equation of thermodynamics:

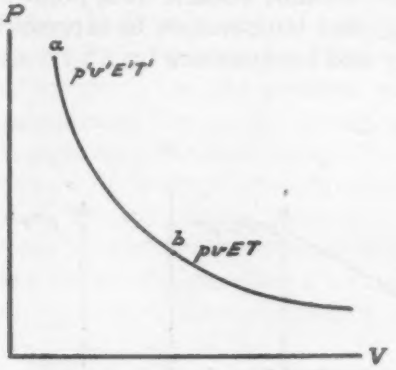
$E'' - E' = K_v(T'' - T') = K_v$; but
$K_v = K_p - C$, but K_p and C are constants; therefore K_v is a constant

X. Adiabatic expansion: When a gas expands or is compressed, without having heat supplied to it, or abstracted from it by external agencies, it is said to expand or compress adiabatically. To prove that pv^γ = constant:

$$\gamma = \frac{\text{Specific heat at constant pressure } (K_p)}{\text{Specific heat at constant volume } (K_v)}$$

On the pressure volume diagram (Fig. F) let m pounds of a perfect gas expand from point a to point b adiabatically, and let point a have an initial pressure, volume, energy, and temperature p', v', E', T', and let point b be any point on the curve with pressure, volume, temperature, and energy p, v, E, T. To deduce the equation of the curve ab between the two points.

FIG. F.



By the first equation $E - E' = - W + Q$, but by definition $Q = 0$; therefore $E - E' = - W$; also

$$E - E' = mK_v(T - T') = - W.$$

In this equation T and W are variables. Taking the derivative with respect to v,

$$mK_v \frac{dT}{dv} = - \frac{dW}{dv} = - p \quad \ldots\ldots\ldots\ldots\ldots\ldots (1) \quad \text{(See III.)}$$

From the combined law of Boyle and Charles $pv = mCT$. Taking the derivative in this equation with respect to v:

$$\frac{d}{dv}(pv = mCT) = p + v\frac{dp}{dv} = mC\frac{dT}{dv}$$

Rearranging, $\frac{dT}{dv} = \frac{1}{mC}\left(p + v\frac{dp}{dv}\right)$.

Substituting this value of $\frac{dT}{dv}$ in equation (1):

$\frac{K_v}{C}\left(p + v\frac{dp}{dv}\right) = - p$. From paragraph VIII, $C = K_p - K_v$.

Substituting this value of C in the above equation:

$$K_v p + K_v v \frac{dp}{dv} = -K_p p + K_v p.$$

Cancelling the common term $K_v p$ and dividing the equation by pvK_v:

$$\frac{1}{p} \cdot \frac{dp}{dv} + \frac{Kp}{Kv} \cdot \frac{1}{v} = 0$$

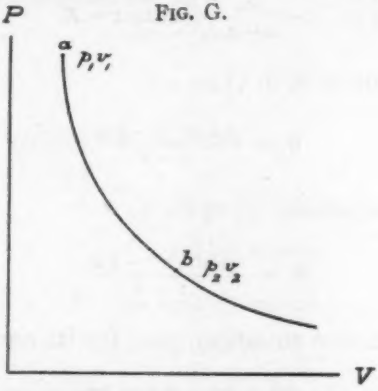
Therefore $$\frac{d}{dv}(\log_e p) + \frac{d}{dv}\left(\frac{Kp}{Kv} \log_e v\right) = 0$$

Substituting (γ) for $\left(\frac{Kp}{Kv}\right)$ in this equation and rearranging:

$$\frac{d}{dv}(\log_e p + \gamma \log_e v) = 0$$

Therefore $\log_e p + (\gamma) \log_e v =$ constant,
Therefore $\log_e (pv^\gamma) =$ constant.
But if the $(\log_e)$ of a quantity is equal to a constant, the quantity itself is equal to a constant.
Therefore $pv^\gamma =$ constant. $\left\{\text{For air } (\gamma) = \frac{Kp}{Kv} = 1.41\right\}$

FIG. G.



XI. All the common cases of expansion and compression follow the law $pv^n =$ *constant.*

For isothermal expansion or compression, the exponent $n = 1$. For expansion or compression at constant pressure, the exponent $n = 0$, and for expansion or compression at constant volume $n =$ infinity.

To find the expression for the work done by a fluid when it expands according to the law $pv^n =$ *constant,* the following solution is given:

On the pressure volume diagram (Fig. G) the curve *ab* represents the expansion of a gas of mass m according to the equation $pv^n = constant$. Let point a have a pressure and volume p_1v_1 and point b a pressure and volume p_2v_2, and let any other point on the curve *ab* have a pressure and volume pv. From paragraph III, $\frac{dW}{dv} = p$. Also from the equation of the curve $pv^n = p_1v_1^n = p_2v_2^n$, therefore, $p = p_1v_1^n \cdot v^{-n}$.

Substituting the value of p given above:

$$\frac{dW}{dv} = p_1v_1^n \cdot v^{-n} = \frac{d}{dv}\left(\frac{p_1v_1^n}{1-n} \cdot v^{1-n}\right)$$

Transposing, $$\frac{d}{dv}\left(W - \frac{p_1v_1^n}{1-n} \cdot v^{1-n}\right) = 0$$

Therefore $$\left(W - \frac{p_1v_1^n}{1-n} \cdot v^{1-n}\right) = \text{constant} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

When $v = v_1$, $W = 0$, as no expansion has taken place.

Substituting in (1) $0 - \frac{p_1v_1}{1-n} = \text{constant} = K$.

Substituting value of K in (1)

$$W = \frac{p_1v_1^n v^{1-n} - p_1v_1}{1-n} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Substituting in equation (2) v_2 for v,

$$W = \frac{p_1v_1^n v_2^{1-n} - p_1v_1}{1-n}$$

Substituting in above equation $(p_2v_2^n)$ for its equal $(p_1v_1^n)$,

$$W = \frac{p_2v_2 - p_1v_1}{1-n} \text{ or } \frac{p_1v_1 - p_2v_2}{n-1}$$

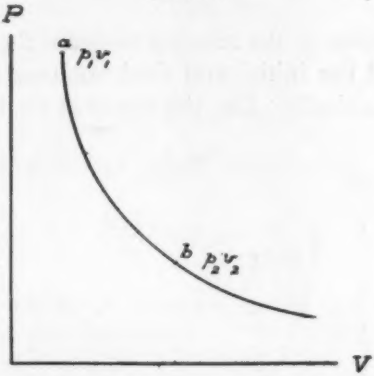
Therefore $$W = \frac{p_1v_1 - p_2v_2}{n-1} = \frac{mC(T_1 - T_2)}{n-1}$$

It is evident that the above formula fails when $n = 1$, when is the case of isothermal expansion or compression.

XII. To find the work done and heat supplied when a perfect gas expands isothermally: The isothermal expansion of a gas follows Boyle's law,—that is, the pressure and volume re-

main constant when the temperature is constant, or during the expansion there is no change in temperature. Let the curve *ab* on the pressure volume diagram (Fig. H) represent isothermal

FIG. H.



expansion of a gas of mass m from pressure and volume p_1v_1 at a to pressure and volume p_2v_2 at b.

$$p_1v_1 = p_2v_2 = pv$$

Therefore $$p = p_1v_1\frac{1}{v}.$$

From III, substituting the value of p,

$$\frac{dW}{dv} = p_1v_1\frac{1}{v} = \frac{d}{dv}(p_1v_1 \log_e v)$$

Transposing, $$\frac{d}{dv}(W - p_1v_1 \log_e v) = 0$$

Therefore $$W - p_1v_1 \log_e v = \text{constant} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Let $v = v_1$, then $W = 0$

Substituting in equation (1) $p_1v_1 \log_e v_1$ for the constant which it equals and transposing,

$$W = p_1v_1 (\log_e v - \log_e v_1) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Let $v = v_2$ and substitute in equation (2)

$$W = p_1v_1 \log_e \frac{v_2}{v_1} \text{ or}$$

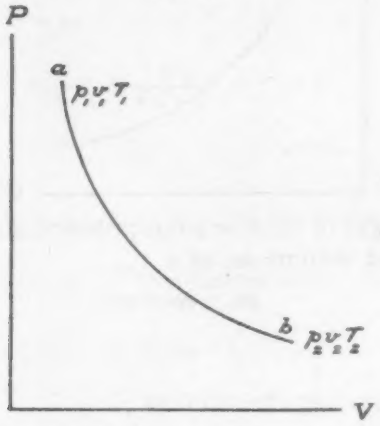
$$W = \frac{p_1v_1}{.434} \log_{10} \frac{v_2}{v_1}$$

Therefore $$W_T = \frac{p_1v_1}{.434} \log_{10} \frac{v_2}{v_1} = \frac{mCT'}{.434} \log_{10} \frac{v_2}{v_1}$$

From the first equation of thermodynamics $E'' - E' = W_T + Q_T$. Since, in isothermal expansion, the temperature remains constant, by Joule's law $E'' - E'$ or $E'' - E' = 0$; therefore $Q_T = W_T$, or the heat supplied is equal to the work done in isothermal expansion.

XIII. Deduction of the relation between the initial and final temperatures and the initial and final volumes of a perfect gas expanding adiabatically: Let the curve *ab* on the pressure vol-

FIG. I.



ume diagram (Fig. I) represent the adiabatic expansion of a gas of mass m, from point a, at pressure p_1, volume v_1, temperature T_1 to point b at pressure p_2, volume v_2, and temperature T_2. From the equation for adiabatic expansion:

$$p_1 v_1^{\gamma} = p_2 v_2^{\gamma},$$

and from the combined law of Boyle and Charles,

$$p_1 v_1 = mCT_1 \text{ or } p_1 = \frac{mCT_1}{v_1};$$

similarly, $$p_2 = \frac{mCT_2}{v_2}$$

Substituting the values of p_1 and p_2 in the first expression above,

$$mCT_1 v_1^{\gamma - 1} = mCT_2 v_2^{\gamma - 1} \text{ or } \frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\gamma - 1}$$

which is the relation, in adiabatic expansion, between the temperatures and volumes.

XIV. Deduction of the corresponding relation between pressures and temperatures:

$$p_1 v_1^{\gamma} = p_2 v_2^{\gamma}$$

Extracting the $(\gamma)^{th}$ root

$$p_1^{\frac{1}{\gamma}} v_1 = p_2^{\frac{1}{\gamma}} v_2$$

From the combined law of Boyle and Charles,

$$v_1 = \frac{mCT_1}{p_1} \text{ and } v_2 = \frac{mCT_2}{p_2}$$

Substituting the values of v_1 and v_2 in the 2nd equation,

$$p_1^{\frac{1-1}{\gamma}} mCT_1 = p_2^{\frac{1-1}{\gamma}} mCT_2$$

Transposing, $$\frac{T_1}{T_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1-1}{\gamma}} = \left(\frac{p_2}{p_1}\right)^{\frac{1-\gamma}{\gamma}}$$

which is the relation between the initial and final temperatures and initial and final pressures when a gas expands adiabatically.

SUMMARY.

In the above deductions, the first equation of thermodynamics,—*i.e.*, $E'' - E' = -W + Q$,—holds good for all substances.

The following equations hold for perfect gases:

$$pv = mCT$$
$$E'' = E' = mK(T'' - T').$$
$$pv^n = constant.$$

In the last equation, for different values of n, the following common expansions obtain:

When $n = 1$ .....Isothermal,
When $n = 0$ .....Constant pressure,
When $n = \alpha$ .....Constant volume,
When $n = \gamma$ .....Adiabatic.

The expression for the work done has two equations, *i.e.*, when n is not equal to 1, and when n is equal to 1.

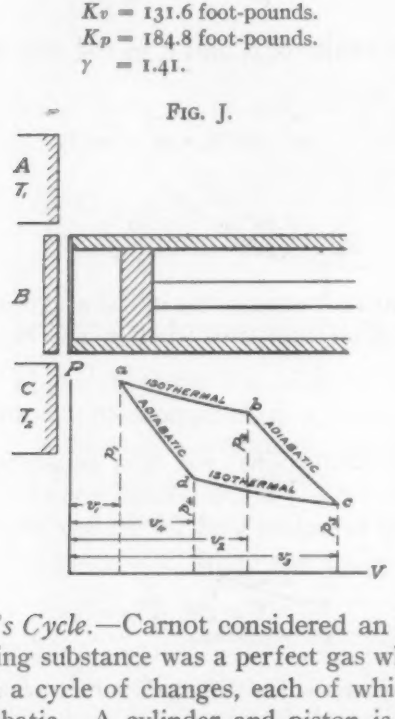
$$W_{n\pm 1} = \frac{p_1 v_1 - p_2 v_2}{n-1} = \frac{mC(T_1 - T_2)}{n-1}$$

$$W_{n=1} = \frac{p_1 v_1}{.434} \log_{10} \frac{v_2}{v_1} = \frac{mCT_1}{.434} \log_{10} \frac{v_2}{v_1}$$

The values of the constants in the above equations—provided p is in pounds per square foot, v in cubic feet, m in pounds, and T in degrees absolute—are:

$C = 53.2.$
$K_v = 131.6$ foot-pounds.
$K_p = 184.8$ foot-pounds.
$\gamma = 1.41.$

FIG. J.



XV. *Carnot's Cycle.*—Carnot considered an ideal engine in which the working substance was a perfect gas which was caused to pass through a cycle of changes, each of which is either isothermal or adiabatic. A cylinder and piston is imagined composed of perfect non-conducting materials, except the head of the cylinder, which is a perfect conductor of heat. In the diagram (Fig. J), A is an indefinite source of heat at constant temperature T_1, B is a perfect non-conducting cylinder head, and

C an indefinite source of heat at constant temperature T_2. T_2 is less than the temperature of the source of heat T_1. It is supposed that A, B, or C can be applied at will to the end of the cylinder.

Suppose the cylinder to contain one pound of a perfect gas at temperature T_1, volume v_1 and pressure p_1.

(1) Apply A and allow the piston to move outward slowly through any convenient distance. The gas expands isothermally at T_1 temperature, and takes in heat from the hot body A, and does work.

The pressure changes to p_2 and the volume to v_2.

(2) Remove A and apply B, allowing the piston to go on moving outward. The gas then expands adiabatically, doing work at the expense of its internal energy, and the temperature falls to T_2. The pressure is then p_3 and the volume v_3.

(3) Remove B and apply C, forcing the piston inward slowly. The gas is compressed isothermally at T_2 temperature, since the smallest increase of temperature above T_2 causes the heat to pass into C. Work is done on the gas and heat is rejected to the cold body C. Let this be continued until a certain point is reached by the piston such that the fourth operation will complete the cycle.

(4) At such point, remove C and apply B. Continue the operation, which is now adiabatic. The pressure and temperature will rise, and if the point at which B is applied has been properly chosen, when the pressure is restored to its original value p_1, the temperature will also have risen to its original value T_1. In other words, the third operation must be stopped when a point is reached such that an adiabatic line drawn through this point will pass through the initial point. This completes the cycle. From the diagram:

$$\left(\frac{v_4}{v_1}\right)^{\gamma-1} = \frac{T_1}{T_2}; \text{ also } \left(\frac{v_3}{v_2}\right)^{\gamma-1} = \frac{T_1}{T_2}.$$

Equating,
$$\left(\frac{v_3}{v_2}\right)^{\gamma-1} = \left(\frac{v_4}{v_1}\right)^{\gamma-1}$$

Therefore
$$\frac{v_3}{v_2} = \frac{v_4}{v_1} = R$$

In other words, the ratio of isothermal expansion equals the ratio of isothermal compression. Let this ratio be denoted by R.

XVI. The efficiency of Carnot's cycle may be deduced in the following manner: From the diagram (Fig. J), and from the preceding paragraph:

Since this is a cyclic process, the first equation of thermodynamics becomes $E'' - E' = 0$, therefore $W = Q$ or $W = Q'' - Q'$. The efficiency is equal to the work done divided by the heat supplied; or,

$$\varepsilon = \frac{W}{Q''} = \frac{Q'' - Q'}{Q''} \text{ but,}$$

$$Q''_T = \frac{mCT_1}{.434} \log_{10} \frac{v_2}{v_1}$$

$$Q'_T = \frac{mCT_2}{.434} \log_{10} \frac{v_3}{v_4}$$

$$Q''_T = mCT_1 \log_e R \text{ and } Q'_T = mCT_2 \log_e R.$$

Substituting these values in equation for ε:

$$\varepsilon = \frac{mCT_1 \log_e R - mCT_2 \log_e R}{mCT_1 \log_e R}$$

Cancelling like terms $\varepsilon = \dfrac{T_1 - T_2}{T_1}$

XVII. *Carnot's Cycle Reversed.*—With the aid of Fig. J, assume that an imaginary engine is to act so that the same indicator diagram as traced in the description of Carnot's cycle is reproduced, but in the direction opposite to that followed in XV. Starting as before from the point p_1v_1 in Fig. J, and with the gas at temperature T_1, the following operations will obtain:

(1) Apply B and allow the piston to move outward. The gas expands adiabatically, tracing the curve on the diagram until the temperature becomes T_2, at the point whose pressure and volume is p_4v_4.

(2) Remove B and apply C. Allow the piston to move outward, expanding the gas isothermally at T_2 temperature, taking heat from C, and tracing the curve to p_3v_3.

(3) Remove C and apply B, compressing the gas adiabatically until the temperature has risen from T_2 to T_1, which will be at the point whose pressure and volume is p_2v_2.

(4) Remove B and apply A, continuing the operation isothermally at T_1 temperature. Heat is, in this last operation, re-

jected to A and the cycle is completed by the curve to the point whose pressure and volume is $p_1 v_1$.

In this process the engine is not doing work. On the contrary, a quantity of work is spent upon it equal to the area of the diagram, or $mC(T_1 - T_2)\log_e R$, and this work is converted into heat. Heat is taken in from C in the first operation to the amount $mCT_2 \log_e R$. Heat is rejected to A in the fourth operation to the amount $mCT_1 \log_e R$. In the first and third operations there is no transfer of heat.

The action is in every respect the reverse of that which occurred in XV. The same work is spent upon the engine as was formerly done by it. The same amount of heat is now given to the hot body A as was formerly taken from it. The same amount of heat is now taken from the cold body C as was formerly given to it. The reversal of the work has been accompanied by an exact reversal of each of the transfers of heat.

An engine from which this is possible is called, from the thermodynamic standpoint, a reversible engine. In other words, a reversible heat engine is one which, if forced to trace out its indicator diagram, reversed in direction, so that the work which would be done by the engine, when running direct, is actually spent upon it, will reject to the source of heat the same quantity of heat as, when running direct, it would take in from the source, and will take from the receiver of heat the same quantity as, when running direct, it would reject to the receiver. By the source of heat is meant the hot body, which acts as the source of heat when the engine is running direct, and by the receiver is meant the cold body, which then acts as receiver.

XVIII. The idea of thermodynamic reversibility is of great interest, for the reason that no heat engine can be more efficient than a reversible engine, when both work between the same limits of temperature. This principle, established by Carnot, is deduced as follows from the laws of thermodynamics: Consider two engines, one reversible and the other non-reversible, and let them work by taking in heat from a hot body A, and by rejecting heat to a cold body C.

If it were possible for the non-reversible engine to be more efficient than the reversible, it would take in less heat from A and reject correspondingly less heat to C in doing each unit of work.

Suppose the non-reversible engine, working direct, be set to drive the reversible engine, as a reversed machine, so that the reversible engine converts work into heat.

With such a condition, for every unit of work done by the engine driving the reversible engine, a greater quantity of heat would be supplied to the source of heat A than was taken from it by the non-reversible engine in driving the reversible engine.

It was shown, however, in Carnot's cycle, that when the engine was operated reversed, the same amount of heat was transferred from the cold body to the hot body as was spent in driving the engine, or as would have been transferred from the hot body to the cold body if the Carnot engine operated direct; hence, with the assumption made above, the hot body would, on the whole, gain heat and the cold body lose an equal amount. Thus, the combined action of the two engines—one working direct and the other reversed—would result in a transfer of heat from the cold body C to the hot body A, which process might evidently go on without limit. The two engines, taken together, form a purely self-acting system, for the entire power generated in one engine is spent on the other and is sufficient to drive the other, and, assuming no mechanical friction, the double machine requires no help from external agencies. Hence the supposition that the non-reversible engine could be more efficient than the reversible engine has led to a result inconsistent with the second law of thermodynamics,—*i.e.*, that it is impossible for a self-acting machine, without the aid of some external agency, to transfer heat from a cold body to a hot body. The conclusion, therefore, is forced that no engine can be more efficient than a reversible engine, when both work between the same limits of temperature.

With the same reasoning, it will be apparent that if both engines are reversible, neither can be more efficient than the other, and hence all reversible heat engines taking in and rejecting heat at the same two temperatures are equally efficient; hence the expression which was obtained for the efficiency of Carnot's engine,—*i.e.*, $\frac{T_1 - T_2}{T_1}$ is the efficiency of any reversible heat engine taking in heat at T_1 temperature and rejecting it at T_2 temperature, and as no engine can be more efficient than one that is reversible, this expression is the measure of perfect ther-

modynamic efficiency. From this expression, therefore, no heat engine can convert into work a greater fraction of the heat which it receives than the difference of the absolute temperatures of reception and rejection of heat, divided by the absolute temperature of reception.

XIX. *Formation of Steam under Constant Pressure.*—The foregoing paragraphs have dealt with the thermodynamic laws with special reference to perfect gases. In the steam engine and steam turbine the working substance is water and water vapor, or steam, the physical properties of which are most conveniently stated by referring to what happens when steam is formed under constant pressure. This is substantially the process which occurs in the boiler of a steam engine when the engine is at work.

For convenience of illustration, assume a cylinder with a quantity of water, which take, say, as one pound, at temperature t_0, and let the piston press on the surface of the water with a force of P pounds per square foot. Let heat now be applied to the bottom of the cylinder. As heat enters the water it will produce the following effects:

(1) The temperature of the water rises until a certain temperature t is reached at which steam begins to be formed. The value of temperature t depends on a particular pressure P which the piston exerts. Until the temperature t is reached, there is nothing but water below the piston.

(2) As heat is added, steam is formed. The piston (which is supposed to exert a constant pressure) rises. No further increase of temperature occurs during this stage, which continues until all the water is converted into steam. During this stage the steam which is formed is said to be saturated. The volume which the piston encloses at the end of this stage,—*i.e.*, of one pound of saturated steam at pressure P and temperature t,—will be denoted by V in cubic feet.

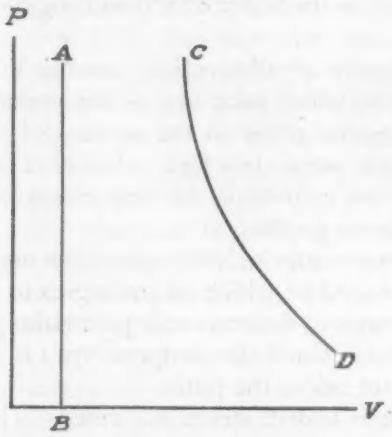
(3) If, after all the water is converted into steam, more heat is allowed to enter the cylinder, the volume will increase and the temperature will rise. The steam is then said to be superheated.

XX. *Saturated and Superheated Steam.*—The difference between saturated and superheated steam may be expressed by saying that if water at the temperature of the steam be mixed with steam, some of the water will be evaporated if the steam is

superheated, but none if the steam is saturated. Any vapor in contact with its liquid and in thermal equilibrium is necessarily saturated. When saturated, its properties differ considerably from those of a perfect gas, but when superheated, they approach those of a perfect gas more and more closely the further the process of superheating is carried on. Saturated steam at a given pressure can have but one temperature. Superheated steam at the same pressure can have any temperature higher than saturated steam at the given pressure.

XXI. *Sensible Heat.*—The amount of heat necessary to raise water from 32° F. to the boiling point (which is dependent

FIG. K.



on the pressure) is represented by h, and is called the sensible heat; therefore, $h = t - 32$.

Latent Heat.—The amount of heat necessary to convert water into steam is called latent heat, and is represented by L. The total heat of steam is, therefore, the sum of the sensible and latent heat, or $h + L - H$.

Wet steam is a mixture of steam and water.

Saturated steam is steam which if compressed a little will partially turn into water.

Dry saturated steam is steam which contains no water.

The physical properties of water and steam may be represented on a pressure volume diagram, such as Fig. K, in which the point B represents the volume of a given amount of water

w. If this water is assumed to be in a cylinder and pressure is put on it, the line AB is traced, which since water is incompressible is parallel to the P axis. All points on the line CD represent dry saturated steam. All points between the lines AB and CD represent wet steam, and all points to the right of CD represent superheated steam. Steam follows very nearly the law

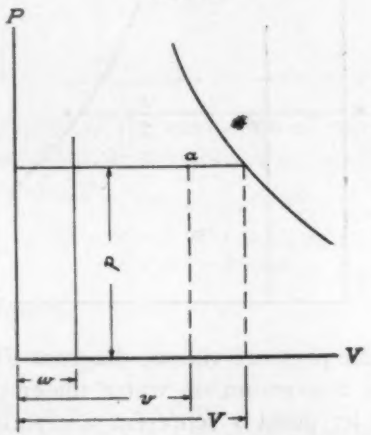
$$pv^{1\frac{1}{16}} = \text{constant};$$

Superheated steam follows the law,

$$pv = mCT \text{ when } C \text{ is equal to } 85.5.$$

XXII. Expressions for latent heat L, total heat H, volume v, and energy of one pound of wet steam: Wet steam

FIG. L.



is said to have a dryness q when the amount of steam present is to the total amount as q is to 1, which may be represented by the fraction $\frac{\text{amount of steam present}}{\text{total amount}} = q$; q is therefore always less than 1, and it is evident that in one pound of wet steam of dryness q there are q pounds of steam and $1 - q$ pounds of water. The latent heat of wet steam is therefore qL, and the total heat of wet steam is $H = h + qL$; also, the volume of water in a mixture of one pound of wet steam is $w(1 - q)$. The volume of steam in the mixture of one pound of wet steam is equal to qV. The total volume is therefore $w(1 - q) + qV = v$.

In Fig. L the point a represents the mixture of one pound of wet steam as referred to above. To determine the expression for the change of internal energy we assume as the starting

point, in dealing with the heat required to produce steam, the state of water as being 32° F.

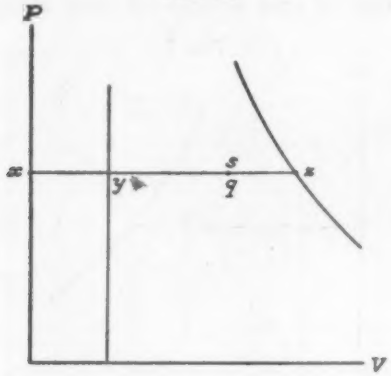
From the first law of thermodynamics, $E'' - E' = -W + Q$.

From the diagram Fig. L, $W = p(v - w)$, and $Q = (h + qL)J$, where J is the mechanical equivalent of heat = 778 foot-pounds. Let E_{32} equal the energy of water at 32° F.

Substituting, in the first equation, $E'' - E_{32} = -p(v - w) + J(h + qL)$, but $v = qV + (1 - q)w$, $v - w = qV + w - qw - w = q(V - w)$.

Substituting this value of $(V - w)$ in the above equation, $E'' - E_{32} = -pq(V - w) + J(h + qL)$.

FIG. M.



XXIII. On the pressure volume diagram Fig. M, let the line xz represent the conversion of water under constant pressure into steam, and let point s represent a certain quality of wet steam with dryness q. To show how the dryness of wet steam is represented on the pressure volume diagram,

$xy = w$ = volume of water present,
$xs = v$ = volume of water and steam at dryness (q),
$xz = V$ = volume of dry saturated steam, therefore,

$$ys = v - w = qV + (1 - q)w - w = q(V - w).$$
$$yz = V - w,$$
$$\frac{ys}{yz} = q\frac{(V - w)}{(V - w)} = q$$
$$sz = yz - ys$$
$$= (V - w) - q(V - w)$$
$$= (V - w)(1 - q)$$
$$\frac{ys}{sz} = \frac{q(V - w)}{(V - w)(1 - q)} = \frac{q}{1 - q}$$

XXIV. The expression for the heat required to form one pound of steam otherwise than at constant pressure may be deduced as follows: Let the curve *ab* on the pressure volume

FIG. N.

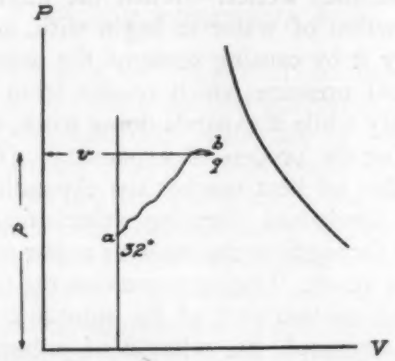


diagram Fig. N represent the expansion of one pound of water from 32° F. to wet steam at *b* with quality *q*. In the first equation of thermodynamics:

$$E'' - E' = -W + Q; \text{ then,}$$
$$Q = E'' - E' + W,$$

From the diagram,

$E' = E_{32}$, therefore,
$E'' = E_{32} - pq(V - W) + J(h + qL)$.
W = area under the curve, therefore,
$Q = E_{32} - pq(V - W) + J(h + qL) - E_{32}$ + area under the curve, or
$Q = -pq(V - W) + J(h - qL)$ + area under the curve.

XXV. *Isothermal Lines for Steam.*—The expansion of volume which occurs during the conversion of water into steam under constant pressure is isothermal. It is obvious that steam, or any other saturated vapor can be expanded or compressed isothermally only when wet, and that evaporation (in the one case) and condensation (in the other) must accompany the process. On the pressure volume diagram isothermal lines for a working substance which consists of a liquid and contains vapor are lines of uniform pressure.

XXVI. *Adiabatic Lines for Steam.*—The form of adiabatic lines on the pressure volume diagram for the substances just de-

scribed depends not only on the particular fluid but also on the proportion of liquid to vapor in the mixture. In the case of steam it has been shown that, if initially dry, it be allowed to expand adiabatically, it becomes wet, and if initially wet (unless very wet), it becomes wetter. When the mixture contains a very large proportion of water to begin with, adiabatic expansion tends to dry it by causing some of the water to evaporate under the reduced pressure which results from the expansion. To keep steam dry while it expands doing work, some heat must be supplied during the process of expansion. If the expansion is adiabatic so that no heat reaches the expanding fluid, a part of the steam is condensed, forming either minute particles of water suspended throughout the mass, or a dew upon the surface of the containing vessel. During expansion the temperature and pressure fall, and, as that part of the substance which remains uncondensed is saturated, the relation of pressure to temperature throughout expansion is that which holds in saturated steam.

(To be continued.)

Cements from Blast-furnace Slag. H. KÜHL. (*Tonind-Zeit.*, xxxvi, 1987.)—There are three classes of cement obtained from blast-furnace slag: (1) *Puzzuolana cements,* which consist of ground slag, containing 42 to 52 per cent. of calcium oxide, mixed with sufficient slaked lime to bring the content of calcium oxide up to 63 to 66 per cent. This cement is hardly superior to a good hydraulic lime, does not harden well in the air, and only feebly resists wear and tear. (2) *True Portland* and *iron-Portland cements*: in the former slag replaces clay in the mixture of raw materials used for making Portland cement clinker. Any slags may be used except such as contain excessive proportions of magnesium and manganese. Iron-Portland cement consists of a mixture of 70 per cent. Portland cement clinker and 30 per cent. of water-granulated blast-furnace slag. In strength and general properties iron-Portland cement is practically equal to Portland cement, but both have the disadvantage of being highly susceptible to chemical action, especially to the influence of sulphuric acid and magnesium salts. (3) *Blast furnace cements* are prepared by mixing rapidly-cooled and granulated slags, which possess innate hydraulic properties, with a considerable quantity of plaster of Paris. Such cements contain only a negligible quantity of free lime, and consequently offer great resistance to the action of acids and magnesium salts.

A BRIEF EXAMINATION OF THE ELECTRICAL PROPERTIES OF EGG-WHITE.[1]

BY E. F. NORTHRUP, Ph.D.

In connection with the subject of the production of electricity by animals, the writer became interested in making a brief examination of the electrical properties of albumen as found in the white of an egg. As the method employed in the test appears to be a good one for biologists to use in making similar tests, and as the results obtained were, to say the least, unexpected, the writer believes his experiment is worthy of record. As only one sample of egg-albumen was examined with care (though three other samples were superficially examined, and these exhibited similar properties), it is considered that the data are insufficient to establish "standard values." The method, however, of making the test is easy to apply and gives results without ambiguity.

A rough preliminary measurement was made to determine the electrical resistance of a fresh hen's egg between two copper wires inserted in the ends of the egg, each wire extending into the egg through its shell about 0.5 centimetre. It appeared at once that the fresh egg was the seat of a considerable electromotive force which would cause a galvanometer of moderate sensibility to deflect off its scale quite violently. By applying 24 volts to the electrodes in the ends of the egg for one minute and then joining these terminals to a millivoltmeter the instrument registered from 0.1 to 0.2 millivolt for the several minutes that it was observed. A fresh egg was selected to which *no* electric potential had been applied, and this also was found to be the seat of an electromotive force of the order of a millivolt. It was apparent that, if the resistance and other electrical properties of an egg (and, as appeared later, even the white of an egg when removed and placed in a container) were to be measured, some method similar to one of the methods used for determining the properties of a cell of battery must be employed. It was thereupon decided to set as the objects of the investigation, to measure (for a single sample) the specific resistance of egg-white, and to determine the residual electromotive force retained

[1] Communicated by the author.

by a specimen of egg-white placed in a Kohlrausch cell, after the sample had been submitted for 600 seconds to 4 volts. It was further decided to trace the curves, called the potential difference curve, the polarization curve, the internal resistance curve, the current curve, and the recovery curve. These curves give the chief electrical characteristics of a battery and are suitable for giving similar information regarding the white of an egg and, presumably, of any sample of an organic fluid.

FIG. 1.

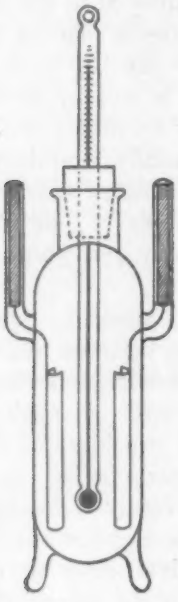
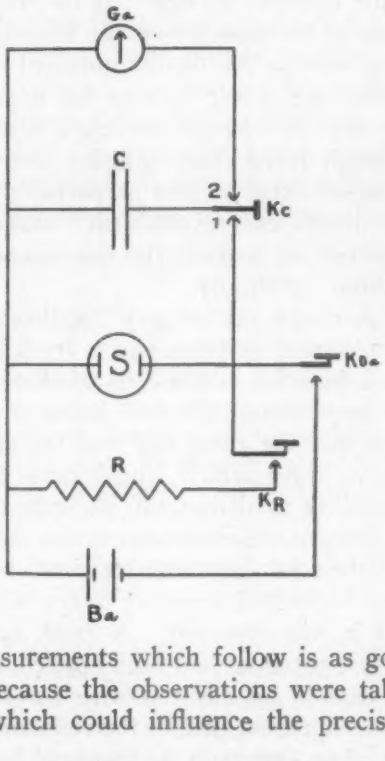


FIG. 2.



The precision of the measurements which follow is as good as the method permits of, because the observations were taken with care and all matters which could influence the precision received attention.

The albumen was taken from a perfectly fresh hen's egg and placed in a Kohlrausch cell of the form illustrated in Fig. 1. The cell had been previously washed out with acid, water, alcohol, and ether, and was quite clean and free from any water molecules. This cell was then placed in the system of electrical circuits shown in Fig. 2.

In these circuits, *Ga* is a D'Arsonval galvanometer used with a telescope and scale. Its deflections, when used as a ballistic instrument, were nearly proportional to the quantity of electricity discharged through its coil. *C* is a mica condenser of 1.5 microfarads capacity. *S* is the Kohlrausch cell containing the egg-albumen to be tested. *R* is a resistance. *Ba* is two cells of storage battery. This could be replaced with a Weston standard cell when it was required to determine the extent of the galvanometer deflection when the condenser *C* is charged to a known electromotive force and then discharged through the galvanometer. K_C is a key which in position 1 charges the condenser and when in position 2 discharges it through the galvanometer. K_{Ba} is a key which when closed submits the contents of the cell *S* to a potential difference of approximately 4 volts. K_R is a key which when closed joins the resistance *R* to the terminals of the cell *S*.

The procedure adopted was as follows: Before any electromotive force had been applied to the contents of *S*, K_C was joined to 1 and then to 2. The galvanometer deflected, indicating that the albumen in cell *S* had a potential. The albumen was then stirred with a glass rod and again tried for a potential. It was found to still have a potential, but a potential *the polarity of which could often be reversed* by stirring. Before stirring, the galvanometer deflected approximately 1.8 divisions toward the left-hand end of the scale, and, after stirring, approximately 2 divisions toward the right-hand end of the scale. As a previous determination of the value of a scale division in volts gave 1 scale division $=$ 0.0096 volt, the albumen was thus shown to be the seat of a potential which before stirring was $1.8 \times 0.0096 = 0.017$ volt in one direction, and after stirring $2 \times 0.0096 = 0.019$ volt in the opposite direction.

The key K_{Ba} was now closed, the other key being open, for exactly 600 seconds. This subjected the albumen to an applied potential of 4.13 volts for this number of seconds. Key K_R was then opened, and immediately thereafter the following program, to give data for the curves, was carried out: With K_{Ba} at all times open, and K_R open, K_C is joined to 1 and the condenser is charged with the potential possessed by the cell *S*. K_C is joined to 2 and the condenser discharged through the galvanometer. The deflection of this is noted. Then K_R is

closed, and after an interval of 1 minute the condenser is again charged and discharged. K_R is now maintained closed for 68 minutes, except that at intervals of two minutes it is opened just long enough to charge and discharge the condenser by means of the key K_C. At these intervals the readings taken give the electromotive force of the cell upon open circuit. The condenser is also charged, K_R being closed, at intervals of two minutes which alternate with the open-circuit readings.

At the end of 68 minutes K_R was opened permanently and open-circuit readings were taken at brief intervals. In this way the data was obtained for plotting the curve of the recovery of the potential of the cell.

All the data obtained by the above procedure was carefully recorded. The values for the electromotive forces in volts, the current in ampères, the resistance in ohms, and the specific resistance are obtained from the relations:

$$E_x = \frac{dx}{ds} E_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where E_s is the electromotive force of the standard cell used and d_s the corresponding deflection, and E_x is any other electromotive force corresponding to the deflection d_x.

$$X = \frac{E - E_1}{E_1} R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where E is the open circuit electromotive force, E_1 the fall of potential over the external resistance R, and X the resistance from terminal to terminal of the cell under test.

$$\gamma_t = \frac{R'_t}{R_t} \rho_t, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

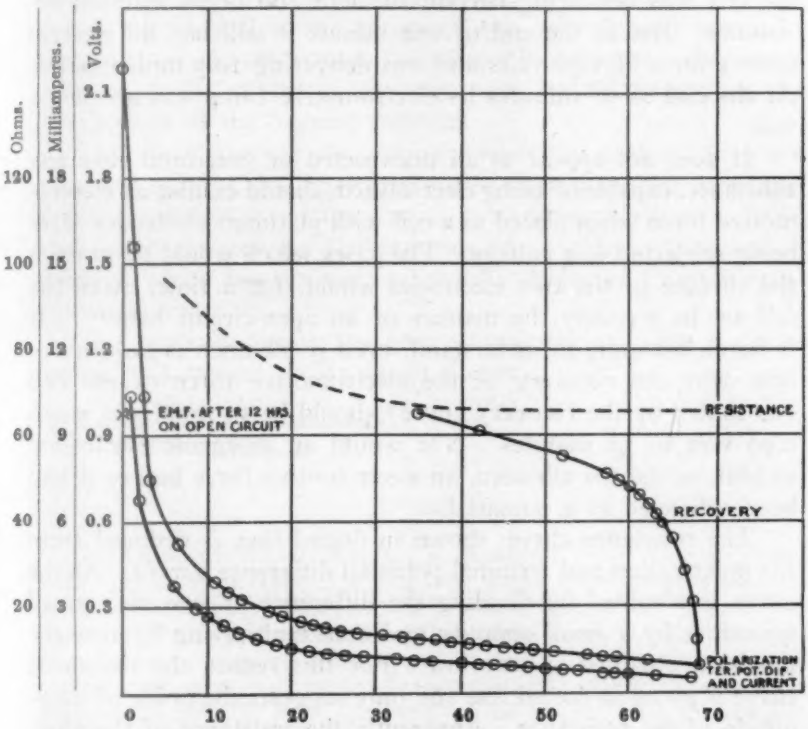
is an equation which gives the specific resistance γ_t (namely, resistance between opposite faces of a centimeter-cube) of the substance at a temperature of t degrees. To obtain the data for solving equation (3) the cell is filled with a saturated NaCl solution of known specific resistance ρ_t. R_t is the measured resistance at temperature t of the cell filled with albumen, and R_t is that of the cell when filled with the saturated salt solution. The resistance of the cell in this latter case is measured by the well-known Kohlrausch method, in which a slide wire bridge,

telephone detector, and current from a small induction coil are used.

The features of interest obtained in this test upon the electrical properties of egg-white are well set forth by the curves (Fig. 3) drawn from the data obtained by the measurements.

In obtaining the data and in drawing the curves the following constant values were used:

FIG. 3.



The resistance R (Fig. 2) was chosen 100 ohms.

The capacity C (Fig. 2) was chosen 1.5 microfarads.

The temperature of the contents of the cell at the time of the test was 22° C.

In reducing the resistivity of the albumen by using formula (3) the value ρ_t assigned to saturated NaCl solution at 22° C. was 4.24 ohms, and the measured resistance of the saturated NaCl solution in the cell was 9.66 ohms. The electromotive force

of the standard Weston cadmium cell used in obtaining the value in volts of the galvanometer deflections was 1.0194 volts. A galvanometer deflection of 1 small scale division was equivalent to charging the condenser to a potential of 0.0096 volt.

The polarization curve shows that immediately after disconnecting the battery *Ba* (Fig. 2), which had applied for 10 minutes 4.13 volts to the cell, the cell retained an electromotive force of 2.2 volts. This electromotive force fell rapidly, because the cell was delivering current through 100 ohms external resistance. But at the end of one minute it still had an electromotive force of 1.56 volts and was delivering 10.5 milliampères. At the end of 68 minutes its electromotive force was about 0.1 volt.

It does not appear at all unexpected or unnatural that any substance, capable of being electrolyzed, should exhibit an electromotive force when placed in a cell with platinum electrodes after being subjected to a voltage. The gases which would form upon the surface of the two electrodes would, for a time, make the cell act in precisely the manner of an open-circuit battery. It is hard, however, to understand, even if albumen is an electrolyte, why the recovery of the electromotive force of the cell (as shown by the recovery curve) should be so rapid and reach 0.99 volt in 33 minutes. Nor would an inorganic electrolyte exhibit, as did the albumen, an electromotive force before it had been subjected to a potential.

The resistance curve, shown in dotted line, is deduced from the polarization and terminal potential difference curves. As the curve is obtained by dividing the difference of two very small quantities by a small quantity and then multiplying by 100, the precision obtained is very low. For this reason the resistance curve is given in dotted line and only suggests the order of magnitude of the resistance. Apparently the resistance of the albumen decreases somewhat with the time. By equation (3) the resistivity can be calculated. Thus

$$\gamma_t = \frac{\rho_t}{R_t} R'_t = \frac{4.24}{9.66} R'_t = 0.439\, R'_t$$

If we call $R'_t = 70$ ohms at 30 minutes as a fair average value, we obtain $\gamma_{22} = 30.7$ as the resistivity for a centimeter-cube of the albumen at 22° C.

Probably a determination of resistivity by an alternating-current method would give a different and lower value, as a very rough test that was made seemed to indicate.

It was found by the writer that, if an egg is subjected to a very high potential, the albumen coagulates about the electrodes. This apparently greatly increases its resistance and very little current flows.

If an extended and more exhaustive investigation were to be made of the electrical properties of albumen, it would be desirable to fill the cell with a saturated salt solution and take data for a set of curves similar to those for albumen. The comparison of the curves in the two cases would bring out the peculiarities of the organic material.

The albumen molecules are altogether too complex to make it safe to suggest any hypotheses based upon this brief investigation as to the nature of the electric conduction of albumen, or to attempt to account for the presence of an electric potential in albumen which has not been previously subjected to an electromotive force.

The observations in the above investigation were made at the writer's request by Mr. H. H. Lester.

PALMER PHYSICAL LABORATORY,
Princeton, N. J.

Corrosion of Water Mains. R. KRZIZAN. (*Z. öffentl. Chem.*, xviii, 433.)—A portion of a cast-iron water main which had been in service for twenty years suddenly became defective. It had been asphalted inside and outside, but the corrosion went right through. A number of conical holes were scattered irregularly over the surface and were surrounded by graphite-like material containing particles of metallic iron. An analysis of the material showed the composition to be: metallic iron 5.98 per cent., ferric oxide and hydroxide 34.09, ferrous phosphate 9.63, ferrous silicate 37.16, ferrous sulphate 0.47, carbon 11.42, sulphur 0.097, manganese 1.362, copper 0.296 per cent. There was nothing in the water running through the pipe to account for this formation. The clay in which the pipe lay contained crystals of gypsum distributed irregularly in it. The corrosion is attributed to local currents set up by contact between the graphite particles and the iron in the presence of a solution of calcium sulphate at the points round the pipe where the crystals of gypsum were contained in the clay.

Fixation of Nitrogen by Alumina and Carbon. S. A. TUCKER and H. L. READ. (*Met. and Chem. Eng.*, x, 475.)—The interaction of pure alumina and commercial bauxite with carbon (petroleum coke) and pure nitrogen was investigated. The charge was heated in a graphite boat, in a graphite tube surrounded by a resistance mass of granular carbon. With pure alumina a product containing up to 30.19 per cent. of combined nitrogen was produced at 1800° C. to 2000° C.; below 1600° C. but little nitrogen was fixed, and above 2000° C. the aluminum nitride decomposed. The nitride, AlN, contains 34.06 per cent. of nitrogen. The presence of appreciable quantities of oxygen, sulphur dioxide, or hydrogen chloride in the nitrogen used is harmful. Producer gas would be a useful source of nitrogen, as the residual gas after the reaction could be burned and used to pre-heat the charge. Some impurities in the charge appear to act favorably, especially iron and lime. It is probable that the first stage of the reaction is the reduction of the alumina by the carbon, and that the nascent aluminum in the presence of fairly pure nitrogen combines with nitrogen preferably than with carbon. The impurities probably act as catalysts in the combination of nitrogen with aluminum. Aluminum nitride, on treatment with boiling water, slowly evolves ammonia, and would probably behave similarly in the soil. By boiling the nitride with alkali solution ammonia would be obtained quantitatively and the residual pure alumina would be available for use or as a marketable by-product. From these experiments there would be no difficulty in manufacturing aluminum nitride containing 30 per cent. nitrogen, as compared with the 17 to 20 per cent. of nitrogen in crude calcium cyanamide (nitrolim).

Neon as a Product of Radioactive Change. W. RAMSAY. (*Chem. Soc. Journ.*, ci, 1367.)—From previous experiments it was concluded that neon is produced when niton, *i.e.*, RaEm, is in contact with water. In this paper further evidence is adduced. The gases evolved from the springs at Bath are shown by analysis to contain 188 times as much neon per litre as ordinary air. This neon is assumed to be produced by the action of niton, as the gases also contain an abnormal amount of this emanation. The experimental evidence is this: 0.103 cubic millimetre of niton was sealed off in contact with a solution of thorium nitrate in about 5 cubic centimetres of water, and allowed to remain for two years. Then the gases were pumped off, and showed the spectra of helium and neon, in the proportion of 0.31 cubic millimetre of helium and about 0.17 cubic millimetre of neon. It was shown by investigation that the neon was not derived from any air which might be presumed to have leaked into the apparatus. Hence neon is produced when niton decomposes in the presence of water. Possibly it is a disintegration product of the niton, consisting of the union of five atoms of helium, or possibly the water is the cause of the reaction.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE PRECISION MEASUREMENT OF THE UNIT OF ELECTRIC CURRENT.

THE completion of the extended research upon the silver voltameter at the National Bureau of Standards makes it desirable and timely to present a brief abstract of the work thus far prepared for publication. The experimental was done by the authors, Messrs. E. B. Rosa, G. W. Vinal, and A. S. McDaniel, of that Bureau.

THE SILVER VOLTAMETER.

PART I.

THE first to make accurate measurements of electric current by electrochemical decomposition was Michael Faraday, who gave the name "volta-electrometer" to the apparatus which comprised his gas voltameter. Poggendorff, in 1847, made use of the silver voltameter, and since his time about sixty papers dealing with this instrument have appeared. The most important of the recent papers have dealt with the researches of the various national standardizing laboratories. It is necessary that the conditions under which the instrument may be used with precision be well understood, since the Electrical Congress, of London, in 1908, adopted the ohm and the ampère as the two primary electrical units, and the "international ampère" is defined in terms of the amount of silver deposited in the voltameter.

The present investigation at the Bureau of Standards began in 1908, and at first was confined chiefly to a comparison of the porous cup and filter paper voltameters. The larger deposits in the latter form over the former for the same quantity of electricity passing were found to be due to the action of the filter paper on the silver nitrate rather than to the previously supposed

* Communicated by the Bureau.

fact that the filter paper allowed complex products formed at the anode to pass through and reach the cathode. The excess of deposit was roughly proportional to the quantity of filter paper present.

The first series of quantitative measurements was made with the small porous cup form, and the results recorded as the voltage of the Weston normal cell at 20° in terms of the voltameter deposits and the international ohm. The value found for the cell at this period of the work was 1.01828 volts.

PART II.

Following the work recorded in the first paper, efforts were made to determine the nature of the action of filter paper on silver nitrate, and a large number of qualitative experiments were made. Fortunately these were possible, since the appearances of the deposit from pure and impure solutions of silver nitrate were quite different. In the former case the deposit is crystalline, while in the latter the deposit is usually striated and may look like slag under the microscope if the contamination is considerable. The important fact was discovered that if the filter paper merely came in contact with the water subsequently used to make up the electrolyte the resulting deposit would be striated.

Various organic substances, such as starch and cane sugar, produced practically no effect, while cellulose always was active even after prolonged washing. This apparent anomaly led to an extended study of the chemical questions involved, the result of which was to show that the oxycelluloses formed decompose into strong reducing agents, such as furfuraldehyde, and these actually precipitate colloidal silver. The existence of this colloid was fully established.

To account for the change from crystalline deposits to non-crystalline striated formations, a theory has been set forth, based on the two fundamental conditions for striations as found by experiment. These are the presence of colloid in the electrolyte and a motion of the liquid (generally due to convection currents) over the face of the cathode.

PART III.

The qualitative work of the preceding paper was followed by quantitative measurements, using chiefly the small porous cup voltameter, which seemed to be the most reliable form at this time. The result of a long series of measurements was to show that the average deviation of a single cup from the mean of two or three cups used under the same conditions was only one part in 100,000. The mean result of 44 determinations of the voltage of the Weston normal cell at 20° was found to be 1.01827_5, which is in close agreement with the result recorded in the first paper. The difference in deposits on gold and platinum cathodes was shown to be negligible. In general the latter were used. Experiments were also made on the temperature coefficient of the voltameter. This, too, was found to be negligibly small, if not zero, when pure solutions were used. The slightly greater deposit in the large size of porous cup voltameter over the small size was found to be due to impurities in the electrolyte.

The usual methods of testing the neutrality of salts do not apply to silver nitrate, but a method of determining the free acid or base to one part in 1,000,000, using iodeosine as an indicator, was found possible. Tests with $\frac{N}{1000}$ potassium permanganate were also devised to determine the amounts of reducing agents and colloidal silver present in the solution. Much work was expended in learning how silver nitrate of a sufficiently high degree of purity might be obtained, but the process cannot be given adequately in the short space available here.

CORRELATION OF MAGNETIC AND PHYSICAL PROPERTIES OF STEEL.

THE co-operation between the Bureau of Standards and the committee on the magnetic testing of iron and steel of the American Society for Testing Materials still continues. This co-operation in the consideration of specifications and in the carrying on of experimental work prevents needless duplication

of work. The standards committee of the American Institute of Electrical Engineers has also agreed to co-operate in this work.

The investigation on the correlation of the magnetic and mechanical properties of commercial steels with a view to discovering some simple magnetic test which may replace some of the mechanical tests and thus avoid the destruction of the material under examination is still in progress. A large amount of data has been collected, and in every case investigated there have been magnetic differences between specimens which had mechanical differences. Without generalizing from the results already obtained, it may be stated that the outlook is very promising. For example, in a certain grade of steel such as is used in springs and tools the magnetic tests showed whether or not it had received the proper heat treatment to give it the desirable mechanical properties.

If the material is not satisfactory, the same magnetic test shows whether the defect is in the nature of too great brittleness or too little mechanical strength. Another test on this same material will show whether it has been subjected to local strains beyond the elastic limit. In another case a steel rail which had broken in service and in which the microscope showed the presence of transverse fissures had a decidedly lower permeability than a similar rail of the same composition which had never been in service and which showed no such transverse fissures. Defects in certain low carbon steel bars have been produced in various ways,—*e.g.*, by bending, nicking, stretching, drilling holes, etc.,—and in every case the good and the defective material have shown characteristic differences.

This work has been carried on with only a limited number of small specimens and by laboratory methods. As this field is almost entirely new, it will be necessary to carry on these preliminary investigations with hundreds of samples, including all the materials that are used in practice. In case the complete investigation fulfils the promise of the part already done, no reason is apparent why the same or similar methods may not be applied to the commercial sizes,—*e.g.*, full-length steel rails.

EFFECTS OF ELECTRIC CURRENTS ON CONCRETE.

By E. B. Rosa, Burton McCollum and O. S. Peters.

Technologic Paper.

THIS paper deals with the results of an extended series of experiments carried out at the Bureau of Standards during the past two years. The investigations consisted of three parts, as follows: (1) Laboratory investigations relating to the nature and cause of the phenomena produced by the passage of electric current through concrete; (2) investigations in the field with a view of establishing the probable extent of the danger in practice, and the circumstances under which the trouble is most likely to occur; (3) a study of the various possible means of mitigating trouble from this source leading to specific recommendations. The experiments were for the most part carried out on cylindrical specimens 6 inches in diameter and 8 inches high with an electrode, usually of iron or other metal, imbedded in the centre, serving as either an anode or cathode in different cases. These specimens were immersed in water in jars surrounded by a sheet-iron electrode, which served as the other terminal.

ANODE EFFECTS.

The tests were carried out with a great variety of voltages, ranging from 2 volts to 115 volts, with the imbedded electrode anode. On the higher voltages, which included all cases having more than about 15 volts per specimen, there was exhibited the familiar phenomenon of cracking of the concrete and rapid corrosion of the imbedded iron, most specimens cracking within 24 hours under a current flow of from 0.5 to 0.8 ampère-hour.

On the low-voltage specimens, however, where the voltages ranged from 2 to 15 volts, very different results were obtained. At the outset of the investigation 90 specimens containing iron electrodes were placed in circuit on 15 volts and watched for a period of seven and a half months. At the end of that time a number were broken open, the amount of corrosion determined, and the general condition of the concrete noted. A most conspicuous feature of the results of this test—and a very surprising one in view of the results previously obtained at higher voltages—is the fact that cracking almost universally failed to occur.

Of the 90 specimens under test only three had cracked at the end of seven and a half months, and these were shown to be abnormal specimens. In practically all cases, also, there was no appreciable corrosion of the iron. It is important to note that the total number of ampère-hours per square inch of imbedded electrode surface in the case of the low-voltage specimens is considerably larger than for the high-voltage specimens, the former averaging 2.6 ampère-hours and the latter only 0.83 ampère-hour. It is evident, therefore, that the quantity of electricity that passes through a specimen does not alone determine the amount of damage that it may do, but that the rate at which the current flows is also an important factor. Moreover, it is evident from these observations that the rate at which damage occurs decreases with decrease in voltage much more rapidly when the voltage is lower, since in the present instance a reduction of voltage to one-fourth of the value used in the high-voltage tests enabled the specimens to run with little or no damage for a period over 200 times as long as was required to destroy the specimens in the higher voltage. It has been shown that this difference in the effect of high and low voltages is fundamentally due to a difference in temperature. So long as the heating effect of the current is insufficient to raise the temperature of the specimen to about 45° or 50° Centigrade, little or no corrosion results, but if the current is strong enough to raise the temperature materially above that point, rapid corrosion sets in.

CATHODE EFFECTS.

When the imbedded electrodes are made cathode, different effects are produced. In this case there is no tendency for the iron to corrode, and the conclusion has been largely accepted that when the current flows from the concrete to the iron no effects were produced. It was found, however, that after such specimens had been in circuit for several months with the iron cathode the bond between the iron and the concrete was practically destroyed. On laying the specimens open it was found that the entire region surrounding the cathode for a distance of one-sixteenth to one-fourth of an inch from the surface of the metal was considerably darker in appearance than the main body of the concrete, and was very soft. The cement here could be shaved off with a knife like soft soapstone.

Experiments with concrete containing no reinforcing material showed that the flow of comparatively heavy currents through the concrete produced no appreciable effect on its mechanical properties. The effects noted above are therefore solely electrode effects, and the softening of the cement at the cathode is attributed to the concentration of sodium and potassium hydroxide near the surface of the cathode, and it is this that causes the softening of the cement. The cracking of the concrete when the iron is anode is due to formation of oxide of iron, and the swelling action thus gives rise to a mechanical pressure which cracks the specimen. The pressure thus produced was measured in several instances and was found to reach values of over 3700 pounds to the square inch.

RISE OF RESISTANCE OF CONCRETE.

It was found that in all cases the resistance of the concrete rose greatly, due to the passage of electric current, the rise being greater in anode specimens than in cathode specimens, the former showing an average increase of 137 times the original value at the end of seven and a half months, and the latter showing an average increase of 14 times the original resistance at the end of about the same period.

The addition of a small quantity of salt to the concrete produced very marked effects. Two or three per cent. of salt added to the water used in mixing the concrete caused the anode specimen to be destroyed very quickly even on very low voltages, because of rapid corrosion of the iron, and also greatly increased the rate at which the softening of the cement at the cathode progressed. The addition of salt likewise reduces the initial resistance of the concrete, and, more important still, prevents the rise of resistance which otherwise takes place under the influence of the electric current.

In discussing the possibilities of trouble from electrolysis in concrete structures under practical conditions, it is pointed out that, while the dangers from this source have often been greatly exaggerated, the possibilities of trouble are nevertheless sufficient to make precautionary measures necessary under many circumstances. A number of possible precautionary measures are discussed in the last section of the paper.

The French Photographic Society announces its fourth competition in color photography, which is open to all photographers, amateur and professional. All classes of work may be submitted, including subjects for window transparencies, lantern slides and stereoscopes. Prints should be accompanied by a description of the subject they represent and the conditions under which they were taken. Numerous medals will be awarded by the jury. The entries close on April 15th next.

Color Photography and Printing. G. BANGÉ A. DUMEZ, and A. DE SEAUVE. (*Eng. Pat. 20,251*, Sept. 12, 1911.)—A set of three color filters is prepared by the use of the following solutions (the quantities are those required for one square metre): *Red*, 64 c.c. of 1 per cent. erythrosin solution, or 10 c.c. of 1 per cent. Bengal Pink solution; *yellow*, 115 c.c. of 1 per cent. Tartrazine solution; *blue*, 5 c.c. of 1 per cent Carmine Blue and 1 c.c. of 1 per cent. Naphthol Green solution. Each filter is also impregnated with about 10 grammes of potassium nitrate per square metre. In conjunction with these filters positive films are employed which can be sensitized with bichromate, the red film consisting of gelatin stained with madder lake and spread on paper to the extent of 8.5 grammes per square metre; the yellow film is impregnated with cadmium sulphide, spread to the extent of 12.8 grammes per square metre, and the blue film is obtained by precipitating a solution of a ferric salt(*e.g.*, by ferrocyanide) and mixing the precipitate with gelatin, using about 6 grammes per square metre. A series of scales of primary colors and of gray, which are photographed at the same time as the subject of the pictures, is also used to check exposures and development of the photographs. The positive films are prepared on paper which has been parchmentized by sulphuric and nitric acid and subsequently dipped in a solution of gum-lac in alcohol.

Variations in Temperature Coefficients of a Precision Balance. J. J. MANLEY. (*Roy. Soc. Proc., Ser. A*, lxxxvi, 591.)—In a previous paper the apparent abnormal behavior of certain precision balances was described and discussed. One point dealt with the displacement of the resting-point of a beam, dependent upon a uniform rise or fall in the temperature of the instrument. The amount of such displacement for a change of 1° C. was termed the "temperature coefficient" of a balance. In this paper attention is directed to changes which may occur in the temperature coefficients of delicate balances. Peculiarities noted with a new balance disappeared after continued careful use of the balance. The conclusion is drawn that before a new, or comparatively new, precision balance can be safely used for obtaining trustworthy values of the highest order of accuracy the instrument must be suitably "aged." A method of effecting this is suggested.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, March 19, 1913.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 19, 1913.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership, 6.

After the transaction of the usual Institute business a joint meeting was held with the Philadelphia Section of the American Institute of Electrical Engineers, President Clark and Chairman Hornor presiding jointly.

The paper of the evening, entitled "The Generation and Distribution of Energy," was presented by Mr. Samuel Insull, President, Commonwealth Edison Company of Chicago.

The speaker described in detail the progress in the economical generation and distribution of electrical current to cities, country towns, and farming communities, and for the drainage of land, power in mines, propulsion of cars on interurban railroads, and other purposes.

He pointed out that economy in the manufacture and distribution of electrical energy is only possible by concentration of production, distribution, and administration.

Numerous lantern slides were shown which gave statistical and other information relating to electrical distribution and consumption.

After a vote of thanks to the speaker the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, March 5, 1913.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 5, 1913.

MR. J. A. P. CRISFIELD *in the Chair.*

The following report was presented for final action:

No. 2523.—Ellis Adding Typewriter. Scott Award recommended. Adopted.

The following report was presented for first reading:

No. 2529.—The Work of Albert Sauveur in Connection with the Metallography of Iron and Steel.

The following applications were accepted for examination:

No. 2530.—Stumpf's Una-Flow Steam Engine.

No. 2531.—Barr's All-Glass Fruit and Preserve Jar.

R. B. OWENS,
Secretary.

SECTIONS.

Section of Physics and Chemistry.—A meeting of the section was held in the Hall of the Institute on the evening of March 6, at 8 o'clock.

Dr. George A. Hoadley occupied the chair.

The Chairman introduced Dr. Arthur W. Goodspeed, Professor of Physics, University of Pennsylvania, member of the Institute.

Dr. Goodspeed gave an instructive lecture on "Electricity and Matter."

He approached his subject by reviewing the work of Sir William Crookes on electrical discharges in high vacua; of Lenard, Hittorf, and Thomson in the same field, and then of the Curies with radium. He showed how this early work led to the theory of the existence of both molecules and electrons.

Dr. Goodspeed gave several experimental demonstrations, one being to show the interception of radium emanation by a fluorescent body in a bath of liquid air.

Several members of the audience questioned Dr. Goodspeed at the close of his remarks.

The thanks of the meeting were extended him.

Adjourned.

WILLIAM E. BULLOCK,
Acting Secretary.

Section of Physics and Chemistry.—A meeting of the section was held on Thursday evening, March 13, 1913, in the Hall of the Institute, at 8 o'clock.

Dr. Harry F. Keller presided.

The minutes of the previous meeting were approved as published.

The Chairman introduced Mr. Arthur D. Little, Chemical Engineer; president Arthur D. Little, Inc., Boston, Mass., who presented an interesting and instructive communication on "The Chemistry of Paper Making."

Mr. Little reviewed the history of the art from the early times of the making of hand-made paper in small sheets to the present manufacture of this substance by improved machinery and highly-developed processes.

He spoke of the methods of manufacturing the various grades of paper; of processes of starching, glazing, coloring, and otherwise treating the product.

An explanation of methods of watermarking and an exhibition of samples of fine production from Russia and Italy proved very interesting.

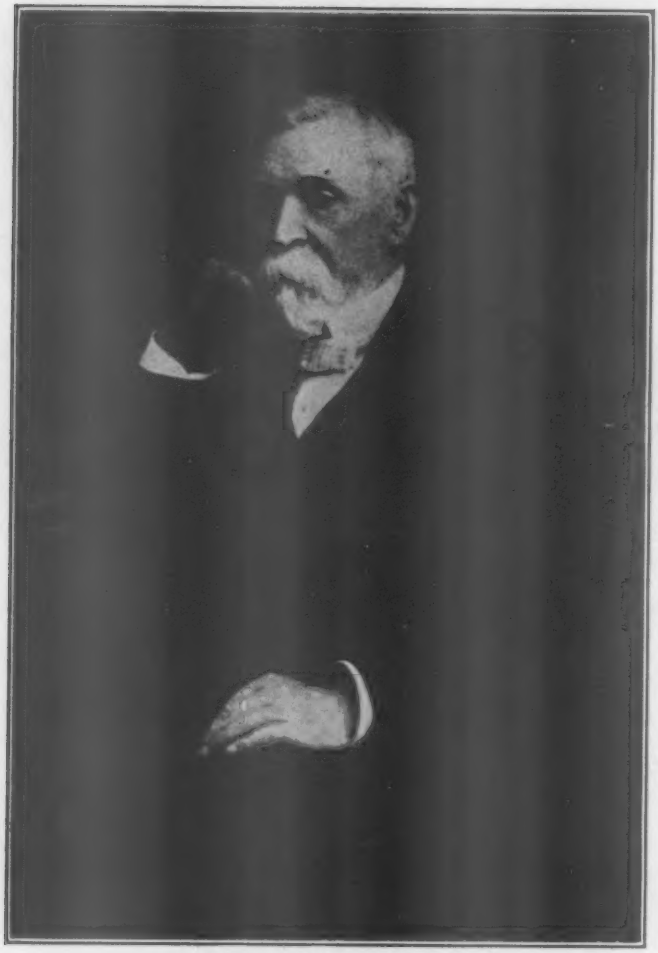
The speaker enumerated the uses of paper, and made some remarks on the future of the paper-making industry.

His talk was illustrated by lantern slides and exhibits.

After a brief discussion, the thanks of the meeting were extended Mr. Little.

Adjourned.

WILLIAM E. BULLOCK,
Acting Secretary.



JOHN FRITZ.
1822–1913.

MEMBERSHIP NOTES.

Elections to Membership.

(Stated Meeting of the Board of Managers, March 12, 1913.)

RESIDENT.

MR. MORRISON COATES NELL, 918 Stephen Girard Building, Philadelphia, Pa.

NON-RESIDENT.

MR. HOWARD N. EAVENSON, Gary, W. Va.
MR. ALBERT R. SHIPLEY, 29 Arch Street, Providence, R. I.
MR. THOMAS TAPPER, 362 Riverside Drive, New York City, N. Y.

ASSOCIATE.

MR. THEODORE W. PINARD, 529 Penn Street, Camden, N. J.

Changes of Address.

MR. WILLIAM C. FARNUM, 131 Oak Street, Winchendon, Mass.
MR. FRANK B. GILBRETH, 71 Brown Street, Providence, R. I.
MR. EDWIN P. GOTWALS, 335 North Broad Street, Lansdale, Pa.
MR. GEORGE R. HALL, 35 Fort Washington Avenue, New York, N. Y.
MR. J. M. HOPWOOD, 98 Fifteenth Street, Wheeling, W. Va.
MR. HUGO LIEBER, 25 Madison Avenue, New York, N. Y.
MR. FRANK G. STANTIAL, 146 Florence Street, Melrose, Mass.
MR. THOMAS TAPPER, 362 Riverside Drive, New York City, N. Y.

NECROLOGY.

JOHN FRITZ.

1822–1913.

In 1910 The Franklin Institute conferred the Elliott Cresson Medal upon John Fritz for "distinguished leading and directive work in the advancement of the iron and steel industries," an additional honor to the many testimonials he received for his engineering ability. He served as president of the American Institute of Mining Engineers and of the American Society of Mechanical Engineers, and was an honorary member of the American Society of Civil Engineers, The Franklin Institute, and other associations. He was chosen vice-president and awarded the Bessemer Gold Medal by the Iron and Steel Institute of Great Britain, and was the first to receive the John Fritz Gold Medal established by the National Engineering Societies.

Born in 1822, he received merely the common-school education which at that time was obtainable in country districts of Pennsylvania, and from early youth he earned his living; but what he undertook he did well, and used his brain as well as his hands to improve methods and processes in iron manufacture. Possibly the best epitome of his achievements was at the celebration of his 70th birthday, when at a mock trial he was indicted for "being a distinguished engineer without technical training"; for he was a good engineer and had not the advantages of technical education.

Although a notable instance of what can be accomplished by individual ability and conscientious effort, John Fritz recognized the value of a thorough education, aiding many to improve themselves and demonstrating his interest by service as a trustee of Lehigh University, supplemented by the Engineering Laboratory, which he built and endowed at an outlay of nearly a quarter million dollars.

His life-work was in iron and steel production and manufacture, some of the most important inventions in this specialty representing the ingenuity of John Fritz. He saw iron production in its infancy; saw it pass from the charcoal into the anthracite and then to the coke era; and saw the production of a blast furnace grow from a few tons to several hundred tons per day. The introduction of the Bessemer and the development of the open-hearth steel processes; the transition from the forge fire or puddling furnaces to gas-fired furnaces of large capacity; from the slitting mill to immense roll-trains, fabricating heavy beams, rails, plates, etc., and from water-operated trip-hammer to hydraulic presses manipulating heavy forgings under pressure rated at thousands of pounds per square inch, are merely some of the advances with which John Fritz was personally familiar and in the development of which he participated.

The presence at his funeral of hundreds of men, representatives of technical societies and of varied industries, evidenced appreciation of his abilities and achievements, and the cessation of industries, the closing of business houses and schools, the funeral escort of the student body of Lehigh University, were tributes of love in his home town, Bethlehem, where he had long resided and where, in his 91st year, he died, honored and revered by all.

J. B.

LIBRARY NOTES.

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CURRENT TOPICS

Penetration of Canal Rays into Solids. J. STARK and G. WENDT. (*Ann. d. Physik.*, xxxviii, 921.)—Several pages are occupied in stating the problem and in its theoretical consideration, and sketches of the apparatus are given. Hydrogen canal rays of kathode-fall up to 5000 volts scatter the *smooth* surfaces of calcspar, fluorspar, glass, and quartz; but they do not destroy the polish. Plates of rock-salt, sylvine, and mica are perceptibly roughened by the impact of slow canal rays. Canal rays of kathode-fall greater than 10,000 volts roughen the surface of fluorspar, calcspar, glass, sylvine, mica, and rock-salt. The surface of quartz is not roughened, yet there is considerable scattering. With calcspar mercury canal rays produce a chemical change in the surface, due to the heating effect; they also produce a scattering effect in all the substances submitted to experiment, without causing a roughening of the surface at the point of impact. The mechanical deep action of the hydrogen canal rays cannot be ascribed to the penetration of the rays through the inter-molecular valency fields under the surface layer. Solid metals are dulled by slow hydrogen canal rays through scattering. The surface of the base of a bismuth crystal is not perceptibly roughened by slow canal rays, and only very slightly by rapid rays; the rays have a much greater scattering effect upon a surface whose plane is approximately perpendicular to this direction.

The Gelatinizing Temperature of Starch Granules. M. NYMAN. (*Zeit. Unters. Nahr. Genussm.*, xxiv, 673.)—Rye, barley, and wheat starches gelatinize at slightly different temperatures,—rye starch at 57° C., barley starch at 58° C., and wheat starch at 59° C. The determinations were effected by placing the starches in water heated to the suitable temperature and, as the temperature rose, removing drops of the mixtures every 30 seconds for examination under the micro-polariscope. The points at which the granules ceased to show interference crosses was taken as the gelatinizing temperature. Experiment showed that the larger starch granules gelatinized more quickly than the smaller. Although the difference in the gelatinizing temperature does not afford a means of identifying two starches in a mixture, the rate of gelatinization may be of some value. For instance, if a mixture of rye and wheat meals is held at 53° C., the rye starch is gelatinized in 6 minutes, while the wheat starch requires 24 minutes; any ungelatinized grains observed after 7 minutes' heating indicate the probable presence of wheat meal.

Active Modification of Nitrogen Produced by the Electric Discharge. R. J. STRUTT. (*Roy. Soc. Proc., Ser. A,* lxxxvii, 179.)—Certain previous observations appeared to suggest that the chemical peculiarities of active nitrogen might be due not to the presence of a definite chemical substance but to the unexplained survival of the conditions of disruptive discharge. Further investigation supports the original view, however. When the active nitrogen is passed through a vacuum-jacketed tube containing a roll of oxidized copper gauze, the gauze becomes heated by the reversion of the active to the ordinary nitrogen, particularly when nitric oxide is mixed with the nitrogen, while the temperature falls if oxygen is admitted instead of nitric oxide. Ionization experiments show that the intensity of the glow is not affected by the removal of the ions, and therefore it is not probable that it is produced by the ions. Local cooling intensifies the glow by accelerating the change, which is proved by dipping a bulb with its tubular neck into liquid air. Hence the active nitrogen appears to be a highly endothermic body, the energy of which is of the same order of magnitude as that of other chemical substances. The ionization is a subordinate effect and might be due to light of very short wave-length emitted during the reversion to ordinary nitrogen; the number of the ionized atoms is a very small fraction of the whole number of atoms concerned in the change. It is suggested that the active nitrogen is monatomic, and that the phenomena may throw light on the connection between temperature and the velocity of reaction.

Heat Transmission. C. H. LANDER and J. PETAVEL. (*Elect. Rev.,* lxxi, 530.)—Describes experiments on the heat lost by hot metal cylinders to surrounding air, the results being applicable to the lagging of steam pipes. The various conditions under which convection, conduction, and radiation assume importance are discussed. All lagging materials conduct better than air and increase the loss due to conduction. They should therefore be packed loosely so as to hold air round the pipe. The lagging can be too loosely packed, as is shown by an experiment on slag-wool lagging of varying densities. The best result is where the wool occupies one-fourteenth of the total space. The loss by radiation per square foot from small pipes diminishes rapidly as the diameter increases, but above 4 inches diameter it becomes nearly constant.

Uses of Peat for Fuel and Other Purposes. C. A. DAVIS. (*Bureau of Mines, Bull No. 16.*)—A comprehensive paper, the scope of which may be thus indicated. The main sections are: Origin and formation of peat; physical and chemical properties of peat as related to its fuel value; preparation and manufacture of peat fuel; peat as a raw material for products other than fuel; tables of analysis; bibliography of peat. For those interested this bulletin is of considerable value.

Naphthalene as Fuel for Explosive Engines. L. VENTON-DUCLAU. (*Mem. et Compte. Rendus des Trav. Soc. Ing. Civ. de France,* lxv, 514.)—Its low price as compared with other hydrocarbon fuels suggests the use of naphthalene. Its percentage of carbon is 93.7, as compared with 92.3 for benzene, and the quantity of air required for the complete combustion of 1 gramme is 13.34 grammes, as against 13.04 grammes for benzene. Since the melting point of naphthalene (79° C.) is well above atmospheric temperature, a special apparatus is required to obtain the explosive mixture of air and naphthalene. The advantages are: (1) low cost, which may be only 0.65 cent per horsepower-hour; (2) security from fire, since naphthalene is only ignited with difficulty even in the liquid state, and a leak of the liquid is not dangerous, as it immediately solidifies; (3) uniformity of composition, as naphthalene is a definite compound. The heat required for melting and vaporizing the naphthalene is obtained from the cooling water or the exhaust gases of the engine, and the engine must be run for the first few minutes with a light fuel, such as petrol, until the parts are warmed up. Hence naphthalene is not suitable where stoppages of any substantial duration occur. Naphthalene has been chosen for fuel for locomotives on the Trans-Siberian Railway, where the water contains fully 5 per cent. of salts. Carburettors for naphthalene are of two principal kinds: (*a*) using naphthalene dissolved in liquid fuel, and (*b*) using melted naphthalene. In type *a* the solid naphthalene is carried in a cage which can be dipped into a reservoir of benzene, alcohol, petrol, etc., the liquid being heated by the engine cooling water or by the exhaust gases. In type *b* the liquid may issue from a spraying nozzle, or the air may be bubbled through the liquid, or the liquid may drop on a heated surface in the air pipe. A single cylinder engine of 140 millimetres diameter and 200 millimetres stroke, fitted with a Bruneau carburettor, used fuel costing about $18.25 per ton. A two-cylinder engine, with cylinders 88 by 140 millimetres, fitted with a Noel carburettor, used fuel costing about $14.25 per ton.

Steam Turbo-generators. ANON. (*Elect. World,* lx, 716.)—*Report of Committee of Assoc. of Edison Illum. Compounds.*—This recounts the progress lately made in designing and arranging steam turbines. The upper limits of speed, outfit, etc., are recorded and compared with the figures obtained a year ago with frequencies of 25 and 60. Special attention is directed to the methods of the Westinghouse Company—*e.g.*, in the improved ventilation of the generators, in the design and construction of the rotors and their winding and insulation, in the maximum voltage (up to 13,000 volts) used directly on the armature windings, and in the means used for bracing the end windings with more security. There is also a description of the means used for supplying cooling air to the generators by blowers or other methods.

Cobalt-chromium Alloys. E. HAYNES. (*Met. and Chem. Eng.*, x, 804.)—Tungsten alloys readily with chromium and cobalt in all proportions, but has little influence in small quantities; above 3 per cent. the alloy becomes harder and more elastic, especially in the presence of small quantities of carbon, boron, or silicon. When the chromium is kept at 15 per cent. a forgeable alloy suitable for cold chisels and wood-working tools is obtained when the tungsten reaches 10 per cent. As the percentage of tungsten rises to 20 per cent. the forgeability decreases, and at 25 per cent. it becomes a very hard alloy, which cannot be forged to any extent, but can be cast into bars and ground to forms suitable for lathe tools, which are very strong and retain their hardness at speeds which instantly destroy the cutting edge of steel tools. An alloy with 40 per cent. of tungsten readily scratches quartz and will turn up, in a lathe, 49 cast-iron wheels without losing its edge; in the same time a steel tool will do only 26 similar wheels, and has to be ground 50 times during the operation. Alloys with similar properties are formed by adding molybdenum to a similar cobalt-chromium alloy. A smaller quantity of molybdenum than of tungsten is required to produce the same increase in hardness.

Philippine Guano. A. J. COX. (*Phil. J. Sci.*, vii, 195.)—Large quantities of phosphate guanos occur in the Philippine Islands, chiefly in limestone caves; the deposits in some caves are reported to reach thousands of tons. The guano is generally bat guano, granular in appearance and gray to brown in color. Its chemical composition is very variable. Good specimens have been found to contain nearly 9 per cent. of nitrogen and over 5 per cent. of phosphoric anhydride and about 1 per cent. of potassium oxide. It is only in unusually dry and well-protected places that the guano remains unleached. In many places the guanos have lost a great part of their soluble constituents (ammonium salts and uric acid), and their value as fertilizers, as given by analysis, is greatly lower than that of the sample quoted above.

Preparation of Natto. S. MURAMUTSU. (*J. Coll. Agric. Imp Univ. Tokyo*, v, 81.)—Natto is a kind of vegetable cheese made by fermenting boiled Soya beans wrapped in rice straw and set in a warm cellar for a few days. The product develops bacteria and becomes white and mucilaginous. It is eaten mixed with condiments. The bacteria are on the surface of the beans, and their spores are not killed by boiling. The straw is used to "supply the good aroma of straw to natto, to take away ammonia," and to facilitate the free access of air to the loosely-packed beans. Three bacilli have been isolated in pure culture with which natto of three qualities can be produced. The mean composition of the dry matter of natto, which amounts to 46.5 per cent., is protein 46, fat 20, fibre 6, nitrogen free extract 3.3, and ash 5 per cent.

Simplicity of the Entropy Chart. W. J. CRAWFORD. (*Power*, xxxvi, 600.)—The simplicity of the entropy chart is emphasized and its more general use is urged. The simplest form of entropy chart (without volume and heat-unit lines) is illustrated, and its use is shown by a number of examples and sketches giving those parts of the whole chart concerned in each case. These examples include the determination of the dryness fraction of steam expanded adiabatically from a stated initial condition (wet, dry, or superheated); the determination of initial dryness (knowing the dryness fraction); determination of the final degree of superheat and of the initial superheat (knowing the final dryness fraction). The representation of a Rankine cycle on the entropy chart is illustrated. The more complex charts used in practice are more confusing at first sight, but are actually more labor-saving.

Ternary Alloys of Magnesium, Zinc, and Cadmium. G. BRUNI and C. SANDONNINI. (*Zeit. anorg. Chem.*, lxxviii, 273.)—Herein are given the results of a micrographic investigation of the ternary alloys of magnesium, zinc, and cadmium. The binary zinc-cadmium alloy shows a eutectic point at 262° C., with 26.5 atomic per cent. of zinc. The cadmium holds about 2 atomic per cent. of zinc in solid solution. Magnesium and zinc form a compound, $MgZn_2$ (melting point 589° C.), and two eutectics, containing respectively 7.5 atomic per cent. of magnesium (melting point 363° C.) and 72 atomic per cent. of magnesium (melting point 340° C.). Magnesium and cadmium give a compound, MgCd (melting point 424° C.), which forms an unbroken series of solid solutions with both components. The compound MgCd exists in two forms, the transition temperature being 248° C. The ternary system has only one true triple eutectic point (250° C., 73 atomic per cent. Cd, 25 Zn, and 2 Mg), and may be divided, as regards primary crystallization, into three areas. The largest range of alloys, covering over two-thirds of the triangular diagram, is that which gives the compound $MgZn_2$. A narrow strip covering about one-fifteenth of the triangle corresponds to primary zinc separation, while the remainder is a region in which a solid solution is the first product to separate. The number of alloys studied was nearly 200, and the paper is illustrated by 40 photomicrographs, which are described and discussed.

Radioactive Elements in Cosmical Systems. S. A. MITCHELL. (*Astronom. Nachr.*, No. 4600.)—The spectra of the sun's atmosphere obtained during the total solar eclipse on August 30, 1905, have been carefully examined for evidence of spectrum lines of radium, the emanation and uranium, as recently suggested by Giebeler and Kayser with regard to the spectrum of Nova Geminorum. No evidence of the presence of the radioactive elements was detected.

Photolysis of Various Classes of Sugars by Ultra-violet Rays. D. BERTHELOT and H. GAUDECHON. (*Comptes Rendus*, clv, 1153.)—The photolysis of ketoses may be effected with rays of longer wave-length than 0.3μ; for aldoses the upper limit is 0.3 to 0.25μ; for open-chain polyhydric alcohols the upper limit is 0.25 to 0.2μ, while cyclic polyhydric alcohols are only decomposed by the extreme ultra-violet rays, of wave-length less than 0.2μ. When these classes of compounds are submitted to the action of rays of the longest wave-length which will effect photolysis, the decomposition proceeds in a simple fashion. From ketoses only carbon monoxide is evolved; from aldoses, two volumes of carbon monoxide and one volume of hydrogen; and from polyhydric alcohols, equal volumes of these two gases. There is no formation of acid nor of substances capable of reducing Fehling's solution in the cold. When, however, rays of shorter wave-length are employed, the product develops acidity and does reduce cold Fehling's solution. At the same time there is an increased production of hydrogen, and some carbon dioxide is formed. Very advanced decomposition causes methane to be produced. Sunlight decomposes ketoses fairly readily, but aldoses only slightly. Solutions of erythritol and mannitol exposed to sunlight for six months evolved no gas, but acquired slight reducing properties. Carbon monoxide and hydrogen, which are primarily formed in simple proportions by the photolysis of carbohydrates, have been shown to combine under the influence of ultra-violet light to produce formaldehyde, the starting point in the natural synthesis of carbohydrates. The photolysis and photosynthesis of formaldehyde are probably reversible processes, and this appears to be true in the case of sugars generally.

The Weighting of Silk with Tin-phosphate. H. LEY. (*Chem. Zeit.*, xxxvi, 1405, 1466.)—Sisley's theory of a preliminary mechanical absorption of the tin-chloride is accepted, but it is suggested that the tin-chloride then undergoes a chemical change within the silk substance, becoming converted into hydroxide, which is at once capable of further chemical combination with the tin-chloride of the bath, forming an insoluble oxychloride. This accounts for the increase of weight with successive baths of "pink-salt," which would not result from mere impregnation. This increase is not mathematically regular, probably owing to the production of a more or less basic tin oxychloride within the silk fibre. The phosphate weighting is regarded as a further chemical reaction, first converting stannic oxide to sodium stannate and then reacting with the free phosphoric acid to form mono-stannic, di-stannic, or tri-stannic phosphate. It is important, from the commercial viewpoint, to remember that the phosphate bath often contains tin salts (*e.g.*, sodium stannate and colloidal tin hydroxide) which are detrimental to the sheen and durability of the silk.

A Speaking Incandescent Lamp. ANON. (*Sci. Amer.*, cvii, 25, 527.)—It has been lately discovered that under certain conditions the incandescent lamp may be made to speak as readily as the arc lamp. According to the *Physikalische Zeitschrift*, Messrs. K. Ort and J. Ridger have used a metal filament lamp as a telephone receiver, employing an Osram lamp of 100 candle-power. The lamp is placed in a 120-volt direct-current circuit including a self-induction coil. Shunted across the two terminals of the lamp are a capacity and the secondary of a telephone transformer, the primary of which connects with a battery of five storage cells and a powerful microphone. Words spoken before the microphone are reproduced in the lamp. The discoverers of this speaking incandescent lamp explain the action on the principle that the telephonic current variations superposed on the current that passes through the lamp produce corresponding variations of heat in the filament, which, radiating to the glass of the bulb, cause the latter to expand and contract proportionately and thus transmit the vibrations to the external air. The effect cannot be produced with 16 or 32 candle-power lamps, because the glass is too thick and the heat variations too feeble.

Vaporization of Metals. J. W. RICHARDS. (*Trans. Amer. Inst. of Metals*, 1912.)—Metals have vapor tension curves similar to that of water. Like ice, the metals have some vapor tension in the solid state. Zinc, boiling at 920° C., has an appreciable vapor tension at 289° C., or 130° C. below its melting point. Silver can evaporate from solid ingots if heated in a flame; the gases carry off some silver vapor. An effective way of checking such volatilization losses is by heating in closed vessels, and especially by the use of the electric furnace.

Rose Culture and the Manufacture of Oil of Roses in Bulgaria. P. SIEDLER. (*Ber. Deut. Pharm. Ges.*, xxii, 476.)—White and red roses are grown; the former are the easier to cultivate, but give only about half as much oil of an inferior quality. The individual growers distill their own oil. Twelve to fifteen kilos. of roses are distilled with sixty kilos. of water until twelve kilos. of distillate are obtained; about eight or nine such lots are mixed and redistilled into flasks with long necks, in which the oil collects on standing. One kilo. of oil is obtained from 3000 kilos. of roses, and 400 roses weigh one kilo. The roses are gathered in the early morning and distilled the same day; usually a mixture of the two kinds is distilled. The pure oil varies in odor and physical properties according to the district in which it is grown, and is skilfully blended by the distributing houses before its sale. The oil is usually adulterated by the peasants, who mix in ginger-grass oil, palma rosa oil, geranium oil, and several other oils. In 1910 there were 3148 kilos. of oil produced.

On the Origin of Planets and their Satellites. BIRKELAND. (*Mon. Sci.*, lxxviii, 853, 64.)—Guided by experimental analogies, M. Birkeland has been led to believe that in the solar systems now in evolution there exist certain forces of electromagnetic origin of the same order of magnitude as that of gravitation, and that these forces, acting in concert, have given birth around the sun to planets having nearly circular orbits, situated approximately in the same plane, to the moons, and to the rings around the planets, and to the nebulæ both in the shape of rings and spirals. The most distant moons, recently discovered near Jupiter and Saturn, with their *retrograde* revolution, do not invalidate this theory; on the contrary, this retrogression suggests that if new planets are discovered sufficiently distant from Neptune, they, too, should have a retrograde revolution around the sun. As the fundamental supposition it is affirmed that all the suns, in comparison with the space of the universe, have an enormous electronegative tension, which differs for the various stars, but which, to give an idea of its magnitude, approximates 600,000,000 volts for our sun and for all suns of a similar class. By means of experimental analogies he endeavors to show how a magnetic field can thus form itself around a star, with its axis the length of its axis of rotation, and how the electric discharges issuing from the central body would, by preference, produce themselves around the equatorial magnetic plane with a continual projection of material electrified particles, which continue their course in the same plane.

The Effect of Acids and Oils on Concrete. W. L. GADD. (*Engineering*, xcv, 20.)—Even exceedingly dilute mineral acids dissolve some of the constituents of Portland cement. Organic acids have less effect, but they combine with the calcium hydroxide liberated when the cement is gauged with water. The author's experiments lead to the conclusion that the addition of oil or fat of any kind to concrete weakens it. Animal and vegetable oils have a direct action on green concrete and finally destroy it, owing to the saponification of glycerides by calcium hydroxide. Indurated concrete is not attacked to the same extent. Mineral oils, though there can be no saponification in this case, weaken mortar to some extent, even when only small proportions of oil are used, and the resulting concrete is less waterproof than dense mortars in which the aggregates are properly graded to fill the voids.

Egypt's Debt to the Engineer. ANON. (*Sci. Amer.*, cvii, No. 23, 477.)—The Assouan dam and other irrigation works in Egypt have cost about $53,000,000; but the increase in the value of land in middle and lower Egypt and the Fayum provinces has been from $955,000,000 to $2,440,000,000. The total rent of this land has risen from $82,000,000 to $190,000,000. This is what the engineer has done for Egypt in less than twenty years.

Photolysis of Various Complex Sugars (Bioses and Trioses) by Ultra-violet Rays. D. BERTHELOT and H. GAUDECHON. (*Comptes Rendus,* clv, 1506.)—Ten per cent. solutions of maltose and lactose exposed to sunlight ($\lambda > 0.294\mu$) for six months suffered no change. When exposed to ultra-violet rays of relatively long wave-length ($\lambda > 0.25\mu$) there was decomposition in two stages, and gases were evolved, two volumes of carbon monoxide to one volume of hydrogen. The solutions remained neutral, did not reduce Fehling's solution in the cold, and had only a slight effect on ammoniacal silver nitrate. When exposed to the extreme ultra-violet radiation the solutions became acid and strongly reducing, and carbon dioxide and methane were among the gases evolved. The gases from maltose contained: carbon monoxide 29, hydrogen 51, carbon dioxide 14, and methane 6 per cent. Lactose, trehalose, and gentiobiose gave almost the same proportions. Trioses are decomposed by the radiation of longer wave-length into two molecules of aldose and one of lævulose, the composition of the gas being approximately three of carbon monoxide to one of hydrogen. This was also observed with raffinose, melezitose, and gentianose. When the rays of shorter wave-lengths are used the composition of the gases changes in the same respects as in the case of the bioses. It is suggested that, since ultra-violet radiations can perform all the functions of enzymes in the scission of sugars and of fats, the reason for the action of enzymes is not to be sought in their chemical structure, but in their vibratory rhythm.

Waterglass Sandstone. W. PUKALL. (*Sprechsaal,* xlvi, 1.)—In 1894 the author concluded that old Persian tiles consisted of a sandstone, and not of a clay, body. Burton has recently come to the same conclusion with regard to old Egyptian ware. Heinecke and Eisenlohr have reached a similar decision in their examination of the tiles in the Omar mosque at Jerusalem. To manufacture these bodies so as to successfully withstand European climates, it is necessary to reproduce artificially the richly alkaline, non-aluminous sandstone. This mixture is recommended: fine sand 100 parts, soda crystals 9, waterglass (of specific gravity 1.38) 12, water 4 parts by weight. The mass is submitted to hydraulic pressure and burned at cone 05. It undergoes a linear contraction of 4.7 per cent., which increases to 8.8 per cent. at higher temperatures.

Amyl Acetate in Bananas. C. KLEBER. (*Amer. Perfumer and Essent. Oil Review,* vii, 235.)—The pulp from a bunch of bananas was distilled with steam and a few drops of oil obtained with a strong banana odor. The oil was hydrolyzed with an aqueous solution of sodium hydroxide and then oxidized with permanganate solution, which produced valeric acid. As silver acetate was obtained from the alkaline aqueous liquid from hydrolysis, the presence of amyl acetate in the original oily distillate was inferred.

India-rubber Production in 1912. S. FIGGIS AND CO. (*London.*)—In 1912 the world's supply of rubber was about 92,000 tons, or, if guayule be included, 99,000 tons; in 1911 the production was 88,000 tons. About 950,000 acres are producing rubber in the East, and about 80,000 acres in Mexico, Nicaragua, and Honduras. The exports from Brazil, Bolivia, and Peru were 50,720 tons in 1912, against 44,170 tons in 1911; about 1000 tons of guayule were exported from Mexico last year. Exports from Ceylon and India amounted to 6300 tons, from Malaya 22,200 tons, and from the West African Coast about 13,800 tons. Imports of rubber into England were:

	Imports. Tons.	Deliveries. Tons.	Stocks, Dec. 31. Tons.
1910	32,659	29,980	5231
1911	33,964	34,054	3954
1912	43,853	44,238	3569

Imports of Parà (Manaos) rubber into England were 11,377 tons in 1912, 11,726 in 1911, and 12,433 tons in 1910, and of Peru (Cauchu) 3792 tons in 1912, 3753 tons in 1911, and 5577 tons in 1910. Of East India and Malay plantation rubber 21,211 tons were imported into England in 1912, as compared with 10,656 tons in 1911 and 6598 tons in 1910.

Pebbles Carried by the Wind. ANON. (*Sci. Amer.*, cviii, 1, 17.)—It has been shown that a wind with a velocity of 23 metres per second can transport through the air particles of sand not exceeding 2 millimetres in diameter. Yet occasionally "rains of stones" of much larger size have been observed. Thus a fall is recorded in the Canton de Vaud of stones of 1½ centimetres in diameter and weighing up to 2.62 grammes. The nearest region whence they could have come was Maures and Esterel. In Château Landon small calcareous stones of 3 centimetres diameter were carried 150 kilometres. In 1883, in Sweden, stones as large as filberts, enveloped in large ovoid hailstones, and weighing nearly 6 grammes, were carried 60 kilometres. Such cases are discussed by M. Thoulet in *Les Annales de l'Institut Océanographique*, and a plausible explanation is suggested. The idea must be accepted of some sort of fixation around the pebbles of an envelope of air or of water vapor. The density of the transported body would then not be that of the pebble but that of the mass of combined solid and fluid (or gaseous) matter, which would be sensibly lighter with respect to its volume.

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